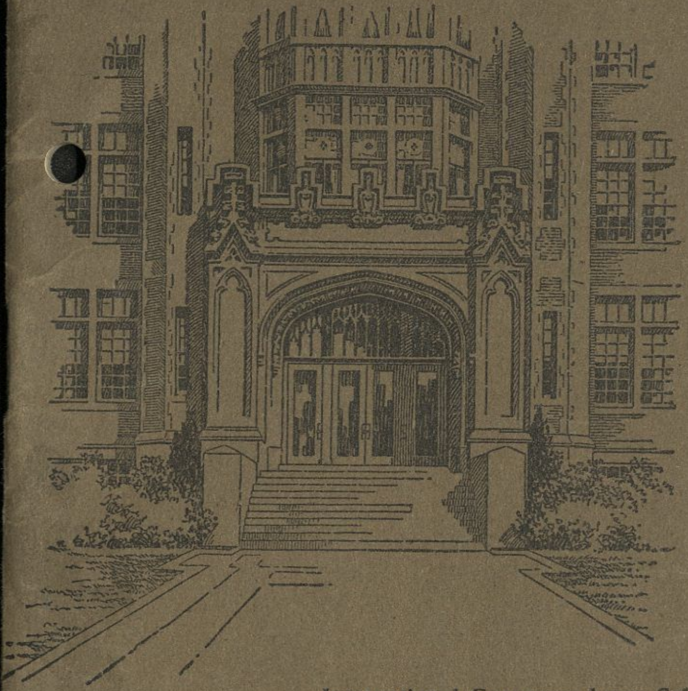

International Correspondence Schools
Scranton, Pa.

# *Heat and Superheaters*

PREPARED ESPECIALLY FOR HOME STUDY

*By*

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DIRECTOR, STEAM RAILROAD SCHOOLS

2504

EDITION 1

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2504

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# HEAT AND SUPERHEATERS

Serial 2504 Edition 1

## HEAT

### MEASUREMENT OF TEMPERATURE

1. **Heat and Cold.**—The terms *hot* and *cold* are commonly used to distinguish between a body that gives one the sensation of warmth and a body that gives the sensation of cold. However, an object only seems warm when it is warmer than the human body, and cold when cooler than the body. Therefore, the senses are not a true indication of the warmth and the coolness of an object. Actually, all objects are heated, except at a certain temperature to be explained later. This means that the difference between an object that seems warm and one that seems cold is that the latter is heated to a lesser degree than the former. Hence, when taken in this sense, the term cold means a certain absence of, but not an entire absence of, heat. Water when boiling is much hotter than a block of ice, but the ice also contains heat.

The natural heat that the surface of the earth and all bodies on the earth possess, is due to the heat received from the sun; that is, solar radiation is responsible for the heated condition of the earth.

2. **Theory of Heat.**—It is supposed that all substances are composed of a large number of particles, called atoms, which are so small that they cannot be seen even by the aid of the most powerful microscope. Atoms, which in turn are made up of

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still smaller particles called electrons, tend to form groups known as molecules.

The position of the molecules with respect to one another depends on whether the substance is a solid, a liquid, or a gas. With a solid like a piece of iron, it is supposed that, if it were possible to see the molecules, they would be found packed closely together as shown in Fig. 1. With a liquid such as water, the molecules, each of which is composed of three atoms as shown in Fig. 2, are supposed to be farther apart, whereas with a gas, the molecules are rather widely separated, as in Fig. 3.

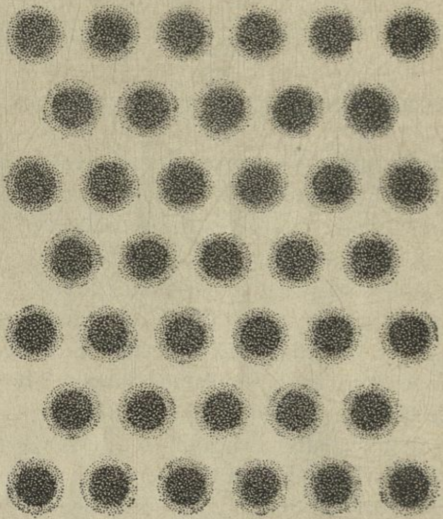


FIG. 1

There is a certain force or attraction between the molecules of a body as well as between the atoms that make up the molecules, which holds them together and causes solid bodies to retain their shape. This attraction is greatest in solids, is less in liquids, and is the least in gases. This lessening of the attraction between molecules is shown by their positions in Figs. 1, 2, and 3, and accounts for the hardness of a solid and for the freedom of movement of the molecules of liquids and gases.

Each molecule of a solid or a liquid body, such as in Figs. 1 and 2, is in continual motion. However, with a solid, the molecules being closer together, their motion is less violent. This motion is called vibration, because it takes place through a very short distance and is then reversed. In the case of a gas as in Fig. 3, the motion is different; each molecule flies practically in a straight line until it encounters another flying molecule. When this occurs there is a rebound and then another flight.

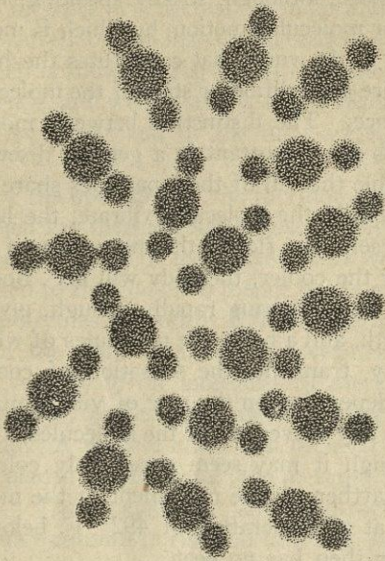


FIG. 2

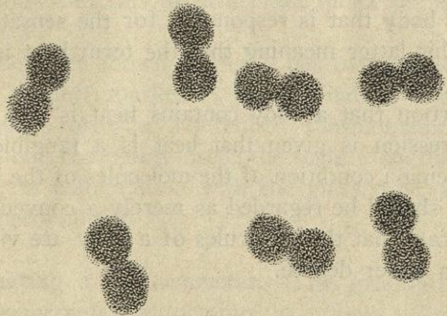


FIG. 3

**3. Definition of Heat.**—The term *heat* is applied to the ceaseless movement of the molecules of which any body or substance is composed, although, strictly speaking, it is the energy of the atomic or molecular motion, by which is meant the ability of this motion to do work, that constitutes the heat of a body. Heat is therefore a condition or state of the molecules that make up any substance. The distinction between molecules, atoms, and electrons is not important in a general discussion of heat, since it is possible that all of these particles share in the motion.

The more rapidly the molecules vibrate, the hotter the body will be; conversely, the slower the movement of the molecules, the less hot, or the cooler, the body will be. Bodies, the molecules of which are vibrating rapidly enough, give one the sensation of warmth, and a body, the molecules of which are vibrating less rapidly, transmits the sensation of coolness, cold, or extreme cold, depending on the rate of vibration. However, as long as there is any movement of the molecules, a body possesses heat, even though it may seem excessively cold to the touch. As explained farther on, the movement of the molecules is supposed to stop at a temperature of 492° F. below the freezing point; the body then has no heat.

Confusion often results from the fact that the term heat is used with two different meanings. Ordinarily, the term is applied to the sensation received from a warm or a hot body; also, the term is applied to the ceaseless movement of the molecules of the body that is responsible for the sensation of heat. It is with this latter meaning that the term heat is here to be regarded.

The assertion that a body contains heat is also misleading, as the impression is given that heat is a tangible substance, instead of being a condition of the molecules of the body. Such a statement should be regarded as merely a convenient expression to indicate that the molecules of a body are vibrating to a greater or a lesser degree.

**4. Temperature.**—The term temperature is used to indicate how hot or cold a body is. Also, as the degree of heat or cold is dependent on the speed of the molecules that compose the body, the temperature is a measure of the speed with which they are vibrating. A rise or a fall in temperature indicates, respectively, an increase or a decrease in molecular speed. Temperature is measured by an instrument called a thermometer, one type of which is shown in Fig. 4. It consists of a glass tube closed at both ends, and with a bulb at the lower end. The bulb and the lower end of the tube are filled with mercury.

The theory of the operation of the thermometer is as follows: When the thermometer is placed, say, in warm water, the vibrations of the molecules of water are communicated to the glass and thence to the mercury, and the molecules of both will finally begin to vibrate at about the same rate as the molecules of water. As the velocity of the molecules of mercury increases, they move farther apart and the mercury is said to expand. A reverse effect will occur if the thermometer is placed in cold water; the mercury will then contract. This expansion and contraction causes the mercury column to rise and fall, and, since equal changes in temperature make the column rise or fall equal distances, the graduations on the scale are made equal throughout. Therefore, a thermometer indicates the rate of vibration of the molecules of a body and this in turn is an index of its temperature.

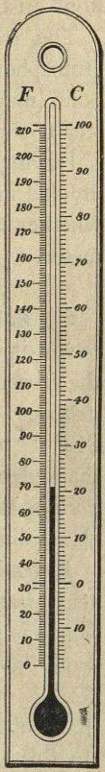


Fig. 4

The thermometer shown in Fig. 4 has two scales. The scale at the left, marked *F*, in combination with the glass tube, forms a Fahrenheit thermometer, which is the one commonly used; the scale *C* on the right forms, in combination with the glass tube, a centigrade thermometer.

**5. Graduating a Thermometer.**—The graduations on the scale of a thermometer are obtained as follows: First, the thermometer is placed in melting ice, and the point to which the mercury column falls at atmospheric pressure is marked and called the *freezing point*. The thermometer is next placed in steam that is escaping from an open vessel and the point to which the mercury rises in the tube is marked and called the *boiling point.* These are two fixed points; that is, the mercury column will always register these same points when the thermometer is placed in melting ice or in steam under the conditions just mentioned.

The freezing point marks the temperature at which, under atmospheric pressure, water freezes and forms ice; the boiling point marks the temperature at which water boils and forms steam when subjected to atmospheric pressure.

Having these two fixed points, the distance between them is divided into equal parts, the number of divisions depending on whether the scale is for a Fahrenheit or a centigrade thermometer.

**6. Fahrenheit Thermometer.**—The Fahrenheit thermometer is made by dividing the distance on the scale between the freezing and the boiling points into 180 equal divisions called *degrees.* The freezing point is marked 32, and the boiling point 212. From the freezing point downwards, 32 divisions are marked off, and the lowest one is marked 0; this is called the *zero point* of the scale. The graduations may be extended above the boiling point or below the zero point as desired.

Instead of writing the word *degrees* after each reading of temperature, it is customary to represent it by the symbol °, which is placed above and to the right of the figures. Also, the word *Fahrenheit* is usually represented by the letter F. Thus, 32° F. means the same as though it were written "32 degrees Fahrenheit"; and 8° F., the same as "8 degrees Fahrenheit." In this thermometer there are 212 divisions between the zero point and the boiling point and $212-32$, or 180, degrees between the freezing point and the boiling point.

**7. Centigrade Thermometer.**—In the centigrade thermometer, the freezing point is marked 0, and the boiling point 100, the distance between the two being divided into 100 equal divisions. As in the Fahrenheit scale, the divisions may be carried above the boiling point and below the zero point. The word *centigrade* is usually abbreviated and written C., as, for example, 10° C., 28° C., etc.

**8. Thermometer Readings.**—Beginning with 0°, the divisions on both the Fahrenheit and centigrade scales are numbered 1, 2, 3, 4, etc., both above and below the zero point. Therefore, in giving the lower readings of a thermometer, it is necessary to state the number of degrees and whether they are above or below zero. To distinguish temperatures below zero from those above, a minus sign is always placed before the former. Thus, 12° means 12° above zero on both scales, whereas −12° means 12° below zero.

**9. Absolute Temperature.**—When the Fahrenheit scale was devised, the zero point of the thermometer was placed 32° below the freezing point, as that was the lowest temperature that could then be obtained, and it was supposed that it was impossible to obtain a lower one. From the results of experiments, however, it has been concluded that at 460° F. below zero, or 492° F. below the freezing point, there is absolutely no vibration of the molecules of any body, and consequently the body has no heat. This point is therefore called the *absolute zero* and all temperatures reckoned from this point are called *absolute temperatures.* Absolute zero has never been reached, although temperatures closely approaching it have been obtained.

**10. Pyrometers.**—Mercurial thermometers cannot be used for the measurement of extremely high temperatures such as exist in furnaces. The instruments used for work of this character are called pyrometers. The type used to determine the temperature of the superheated steam in locomotive practice makes use of the thermocouple principle, by means of which an electric current proportionate to the difference in temperature between the hot and cold junctures of the couple is generated. The indicator itself contains a millivoltmeter actuated by the current generated at the thermocouple and moves a pointer on the dial, thus indicating the actual temperature of the steam.

**11. Quantity of Heat.**—It has already been stated that heat is the term applied to the vibration of the molecules of a body; thus, heat is a condition of matter. The term quantity of heat is therefore not strictly correct, because it implies that heat is a substance and is something tangible. However, *quantity of heat* and *amount of heat* are terms that are found in all discussions on this subject, and although somewhat misleading, they are very convenient terms to use.

A study of the following will give an idea of what is meant by quantity of heat: Let it be assumed that a pint of water and a quart of water are each heated over a gas flame of the same size, thereby insuring that both are subjected to the same heat. It will be found that the pint of water will reach the boiling point first, and that heat must be applied to the quart of water for some time afterwards before the water will commence to boil. With the water in both boiling, a thermometer inserted in each one will indicate the same temperature. But heat has been applied for a longer time to raise the quart of water to the boiling point, hence it is said to contain a greater amount or quantity of heat than the pint of water. The explanation is that it necessarily requires more heat to put the larger number of molecules in the quart of water in the same state of vibration as the smaller number of molecules in the pint of water. That the temperature of both is the same is an indication that the molecular vibration of water is equal in both vessels.

Therefore, of two bodies of the same temperature and under the same pressure, the one that has the greater number of molecules, that is, the one that weighs the more, will contain the more heat. A thermometer alone is no guide in determining the quantity of heat that a body contains; this instrument only indicates the rate at which the molecules are vibrating, or the temperature. To determine the quantity of heat, not only the temperature but also the weight of the water must be known.

**12. British Thermal Unit.**—Just as a pound has been taken as a unit of weight, and a foot as a unit of length, so a unit for measuring the quantity of heat has also been established. An increase in the temperature of one pound of pure water from 62° F. to 63° F., or one degree, is taken as the quantity of heat unit. That is, the quantity of heat already in one pound of water is increased by one unit when the temperature of the water has been increased as stated. The name given to the quantity of heat unit is the British thermal unit, abbreviated B. t. u.

In defining the unit of heat, it is necessary to specify the temperature of the water, because the amount of heat necessary to raise one pound of water through one degree varies slightly with the water at different temperatures. However, the variation is so slight that, for most practical problems, the unit of heat may be taken as the quantity of heat required to raise the temperature of one pound of water one degree without reference to any particular temperature.

It has already been stated that any substance contains some heat except at absolute zero, or 492° F. below the freezing point. However, when calculating in heat units the quantity of heat a body contains, it is assumed that water at the freezing point, or at 32° F., contains no heat. Therefore, if the temperature of one pound of water at 32° F. is increased to 33° F., the water is said to contain a quantity of heat equal to one unit, or one B. t. u.; if increased from 33° F. to 34° F., two heat units, etc. If the water is heated from 32° F. to 212° F., or to the boiling point, the water would be raised $212-32$ or 180 degrees; hence one pound of water would contain a quantity of heat equal to 180 B. t. u., or one B. t. u. for each degree the temperature of the water has been increased. One hundred pounds of water at the boiling temperature would contain $100 \times 180$ or 18,000 B. t. u.

**13. Determining Heat Units in Fuels.**—Having selected a definite quantity of heat unit; namely, the heat required to raise the temperature of one pound of water one degree Fahrenheit, it is possible to determine the number of heat units in a sample of coal. This is done by so burning the coal that its heat is communicated to a certain weight of water; then, by observing the rise in temperature, the heating value of the coal in B. t. u. can be readily calculated. A device for determining the heating value of coal is known as a *coal calorimeter*.

The following gives, in a general way, the arrangement and operation of such an apparatus; a detailed explanation is beyond

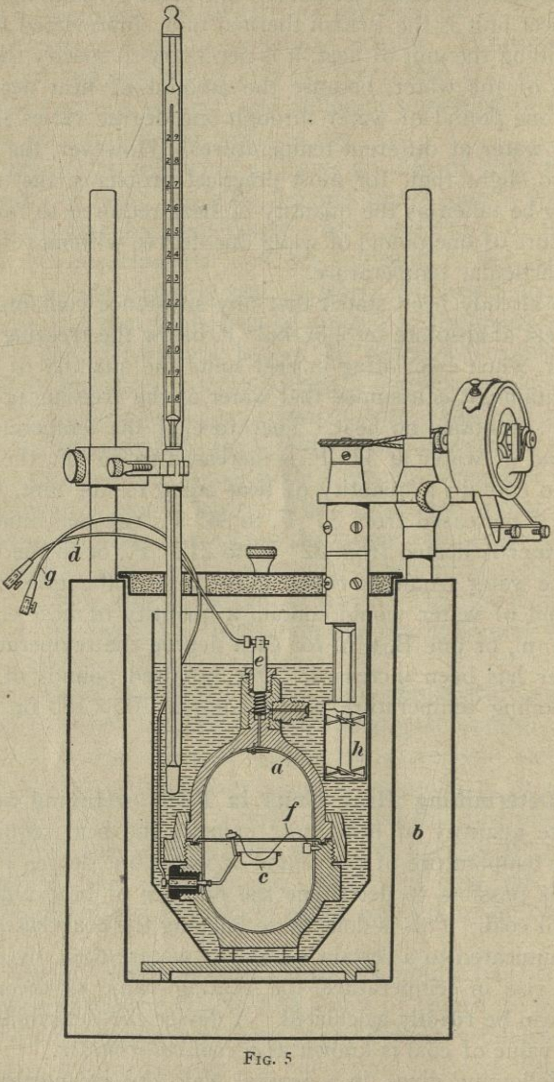


FIG. 5

the scope of this paper. As shown in Fig. 5, the calorimeter consists of a strong steel receptacle *a*, called a bomb, that is immersed in water in a tank *b*. The sample of coal is placed within the bomb on a nickel or platinum pan *c*. The bomb is charged with pure oxygen at a high pressure through the piping *d* and the valve *e*. When the pressure in the bomb rises to about 300 pounds, the oxygen supply is cut off from the piping, and the valve *e* is then closed. The coal is ignited by means of the fuse wire *f*, which is heated by passing an electric current through the wire *g*; and, owing to the presence of the oxygen, the sample will be completely burned.

The weight of the water in which the bomb is immersed is known, as well as the weight of the coal. Then, with the increase in the temperature of the water indicated by the thermometer shown, it becomes an easy matter to calculate the heating value of the coal.

For example, it is assumed that the sample of coal weighs .004 pound, that the water weighs 4 pounds and that the temperature increases 12° F. The quantity of heat absorbed by the water is then $12 \times 4$ or 48 B. t. u. However, only .004 pound of coal was burned; if a whole pound were burned, the heat produced would have been equal to $\frac{48}{.004}$ or 12,000 B. t. u.; this, then, is the heating value of the coal.

The stirring device *h*, driven by the motor shown, is to keep the water agitated and thus secure as uniform a temperature throughout the water as possible. The tank is usually surrounded with a jacket having a vacuum wall, so that there will be a minimum exchange of heat between the tank and its surroundings.

**14. Sources and Generation of Heat.**—There are two main sources of heat: one source is the heat obtained from the burning of coal, gas, and oil or its distillates, gasoline and kerosene; and the other source is water power, from which electricity is generated for heat and light. As yet no means has been found to make available for commercial use the heat received from the sun.

The generation of heat in the first instance is brought about by the union of the oxygen of the air with the elements, carbon and hydrogen, which make up the larger part of such fuels as wood, coal, and oil. When the fuel is heated sufficiently, the oxygen unites with the carbon and the hydrogen to form products that are entirely different from those that entered the union, and burning, or combustion, is then said to have taken place. Burning, or the union of the oxygen with the carbon and the hydrogen, is accompanied, for reasons not yet fully understood, by an intense vibration of molecules, or by heat.

**15. Heat of Combustion.**—The proportion of carbon and hydrogen in the fuel determines the quantity of heat that is generated during combustion. Hydrogen when burned evolves over four times as much heat as carbon, hence fuels that are rich in hydrogen, such as oil and gasoline, have a much higher heat producing value than coal, in which the carbon content largely exceeds the hydrogen.

The quantity of heat obtained from the burning of one pound of hydrogen is 62,000 B. t. u.; that is, enough heat is generated to raise the temperature of 62,000 pounds of water one degree. The burning of a pound of good coal produces about 14,500 B. t. u., or enough heat to raise 14,500 pounds of water one degree.

The burning of carbon may be complete or incomplete, depending on the proportion of oxygen which unites with the carbon. If one part, by volume, of carbon unites with two parts of oxygen, the resulting product is carbon dioxide. The combustion is then said to be complete, because carbon dioxide cannot be burned. For every pound of carbon that is so burned, 14,500 B. t. u. is generated. If one part, by volume, of carbon unites with only one part of oxygen, the resulting product is carbon monoxide. Combustion is then said to be incomplete, because more oxygen might have been combined with the carbon, and because the carbon monoxide is also capable of being burned. Only 4,400 B. t. u. is produced when carbon burns to carbon monoxide.

## TRANSMISSION OF HEAT

**16. Transfer of Heat.**—The term *transfer of heat* means the transfer of the vibration of the molecules of one body to another body, thereby causing a vibration of its molecules. Heat may be transmitted from one place to another in three different ways; namely, by conduction, by convection, and by radiation or by a combination of two or more of these methods.

**17. Conduction.**—Conduction is the transfer of heat from a place of higher temperature to a place of lower temperature in the same body without motion of the body as a whole, or from one body to another with which it is in contact. Thus, if one end of a short iron rod is placed in a hot fire, the entire rod will soon become warm, owing to the fact that the vibration of the molecules in the heated part of the rod is communicated to the others throughout the length of the rod.

**18. Convection.**—Convection is the transfer of heat by motion of the particles of the heated substance. The transfer of heat by convection occurs only in liquids and gases. For example, if heat is applied to the bottom of a vessel that contains water, the water in contact with the bottom becomes heated and rises, while the colder water above descends. A circulation is thus set up by which the heated portions of the water continually carry heat to other points in the vessel. Thus, by the process of convection, the entire mass of water at length becomes heated.

**19. Radiation.**—The heat from an electric globe can be felt when the hand is held beneath it. As the hand is not touching the globe, the heat experienced is not due to conduction, neither is it due to convection, because the air which would carry the heat, rises when heated. Heat is said to be transferred by radiation when it is carried across a space without the aid of any material substance; such heat is called *radiant heat*. As yet, science is unable to offer an explanation of the transfer of heat by radiation.

Examples of radiant heat are very common. A person standing in front of a fire but at some distance from it feels a sensation of warmth which is not due to the temperature of the air, because if a screen is placed in front of the fire, the sensation immediately ceases. The heat from the sun reaches the earth by radiation.

The transfer of heat by conduction and convection is very slow, whereas with radiation it is very rapid. Radiant heat travels at the same speed as light, or about 186,000 miles a second.

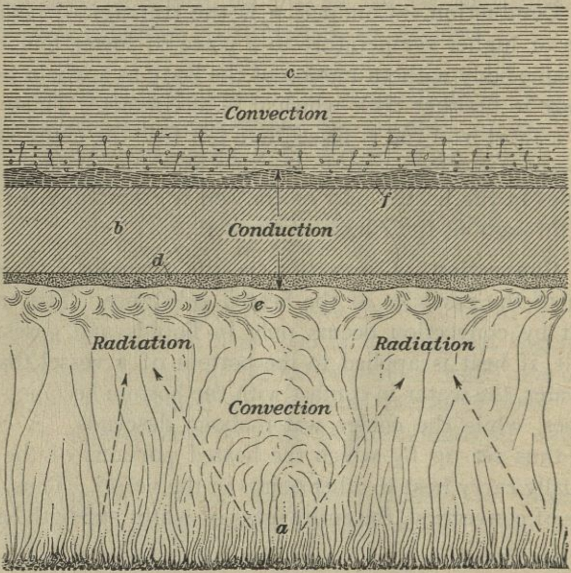


FIG. 6

**20. Heat Transfer in Boiler.**—As shown by the diagram in Fig. 6, the transfer of heat from the burning fuel to the water in a boiler is accomplished by radiation, conduction, and convection. The burning of the fuel at *a* gives an incandescent fire from which heat is radiated against the sheet *b* of the boiler. The radiant heat heats the surface of the sheet, then the whole sheet is heated throughout by conduction. The hot gases that arise from the fire heat the gases in the firebox by convection. These hot gases then come in contact with the sheet and also heat it by conduction.

The water in direct contact with the sheet is heated because the sheet has already been heated by conduction. The water then rises, cooler water takes its place, and the heat is carried through the whole body of the water *c* by convection, owing to the rising of the warm water currents.

The scale *f* that collects on the water side retards the passage of heat from the sheet to the water. To promote the rapid transmission of heat, the sheet should be kept as free as possible from scale. In actual operation, a coating of soot *d* collects on the fire side of the plate and retards the flow of heat from the hot gases *e* to the plate.

If the sheet is too thick, the conduction of heat through it will be slow; hence the heat will not be absorbed as rapidly by the water, and the firebox side of the sheet will become overheated. For this reason the sheets of the firebox are not made thicker than $\frac{3}{8}$ inch or $\frac{7}{16}$ inch.

## FORCE AND WORK

**21. Force.**—Force is defined as that which causes or tends to cause motion. Any push or pull exerted against a body, whether sufficient to move it or not, is an example of force. Force is exerted when any object is moved from one place to another.

Examples of force are very common. A locomotive is exerting force when pulling a train, and the steam in the cylinders of the locomotive is exerting force on the pistons and is causing them to move.

Another example of force is that of gravity. The force required to lift or to sustain an object in the hand is usually ascribed to its weight. In reality it is the force of gravity or the attraction of the earth upon the object, tending to pull it back to the earth, that is responsible. In the absence of the force of gravity, an object would not have weight, hence the weight of a body is merely a measure of the pull or force that gravity is exerting upon it.

**22. Work.**—Work is said to be performed when the body to which force is applied, is moved. Thus, work is performed when an object is raised from the floor and placed on the table, because a great enough force is applied to the object to move it. Therefore, two conditions are necessary before work can be performed; first, there must be force, and second, there must be motion, and motion implies distance.

Since work is a combination of force and distance, a convenient unit for the measurement of work can be established by combining the units of force and distance. The unit for measuring force is the pound, and the unit for measuring distance is the foot; hence, the unit of work is taken as the foot-pound. An amount of work equal to one foot-pound is performed when one pound is raised one foot, or when a force of one pound is applied through a distance of one foot. A weight of 100 pounds lifted 10 feet would represent an amount of work equal to $100 \times 10 = 1{,}000$ foot-pounds. A locomotive that developed a drawbar pull of 20,000 pounds when moving a train 1,000 feet has performed work equal to $20{,}000 \times 1{,}000$ or 20,000,000 foot-pounds.

In all cases, the work performed is equal to the force multiplied by the distance through which the force acts or stated as a formula

$$\text{work} = \text{force} \times \text{distance}$$

**23. Rate of Doing Work.**—The time element, or the slowness or quickness at which work is done, does not enter in any way into calculations involving the amount of work performed. For example, the amount of work performed in raising 500 pounds of wheat 2 feet is 1,000 foot-pounds, and is the same whether the wheat is raised in 1 minute or in 5 hours. A child could raise the wheat, lifting a little at a time, and he would do as much work as a man who could raise 100 pounds at a time. However, the time consumed by the child in doing the work will be much greater than that required by the man.

The term *rate of doing work* means the amount of work done in a unit of time, and is calculated by dividing the amount of work done by the time in minutes required to do it, or written as a formula

$$\text{rate of doing work} = \frac{\text{force} \times \text{distance}}{\text{time in minutes to do work}}$$

As distance in feet divided by time in minutes is equal to velocity, the foregoing formula may also be written as follows:

$$\text{rate of doing work} = \text{force} \times \text{velocity}$$

The rate at which a locomotive is doing work with a drawbar pull of 20,000 pounds and moving 1,760 feet per minute, or 20 miles per hour, is equal to $20{,}000 \times 1{,}760 = 35{,}200{,}000$ foot-pounds per minute.

**24. Unit of Rate of Doing Work.**—The rate of doing work is taken as the number of foot-pounds of work done in one minute. The unit of rate of doing work is the horsepower and represents the performance of 33,000 foot-pounds of work in one minute. With so many foot-pounds to represent a horsepower, the solution of problems involving horsepower will result in small numbers.

When applied to a locomotive, the unit of rate of doing work is generally referred to as the drawbar horsepower. To calculate the horsepower or the drawbar horsepower, it is merely necessary to divide the rate at which work is being done by 33,000, or stated as a formula

$$\text{rate of doing work in horsepower} = \frac{\text{rate of doing work}}{33{,}000}$$

Example.—The drawbar pull with a locomotive moving at 25 miles per hour is 24,000 pounds. What drawbar horsepower is the locomotive developing?

Solution.—A speed of 25 mi. per hr. is 2,200 ft. per min., hence the rate at which work is being done is $\frac{24{,}000 \times 2{,}200}{1} = 52{,}800{,}000$ ft.-lb. per min. The drawbar horsepower is then equal to $\frac{52{,}800{,}000}{33{,}000} = 1{,}600$ hp. Ans.

The tractive force of a locomotive is calculated by the use of the formula, work = force × distance. To illustrate, it is here assumed that a locomotive has cylinders of a diameter of 26 inches, a stroke of 28 inches, driving wheels of a diameter of 63 inches, and a steam pressure of 200 pounds. The first step is to find the amount of work that is being performed at the crankpin on one side. This is equal to the average pressure on the piston multiplied by the distance through which the force acts for one turn of the wheels. This distance is equal to twice the stroke.

The average pressure on the piston is found by multiplying its area, or 530.9 square inches, by 85 per cent. of the boiler pressure, or 170 pounds; hence the average pressure on the piston is equal to 90,253 pounds. This force acts through 56 inches, or twice the stroke. The work performed at the crankpin is then equal to 90,253×56 or 5,054,168 foot-pounds.

With the amount of work performed at the crankpin known and the distance through which this force acts, or the circumference of the wheel, also known, the force developed at the rim of the wheel, or the tractive force, is equal to 5,054,168 divided by 197.9, the circumference of the wheel in inches, or 25,539 pounds. However, only one side of the locomotive has been taken into account in the foregoing; with both sides considered the tractive force becomes equal to 25,539×2 or 51,078 pounds.

## RELATION BETWEEN HEAT AND WORK

**25. Mechanical Equivalent of Heat.**—If the hand is rubbed vigorously on a table for a few minutes, a sensation of warmth is obtained. Also, a bar of iron will become heated when hammered rapidly with a hammer, because this action increases the rate of vibration of the molecules of the bar. For the same reason, or owing to increased molecular vibration, the journals of cars unless kept well oiled will soon heat to such an extent as to ignite the packing. In all the above cases, work is being performed, therefore a relationship exists between work and heat; that is, work can be changed into heat.

Heat can also be changed into work, because the heat, or the intense vibration of the molecules that accompanies the combustion of fuel in a locomotive firebox, is changed into work in the cylinders. The vibration of the molecules in the firebox is communicated to the water in the boiler with the result that particles of water called steam are expelled. The vibration of these particles in turn causes a pressure to be exerted on the pistons and moves them. Therefore, the heat, or the vibration of the molecules, that accompanies combustion appears finally as a pull at the drawbar. In other words, the firing of a scoop of coal into the firebox is but the beginning of a series of actions and reactions that end with the delivery of power at the drawbar. The foregoing is shown graphically in Fig. 7.

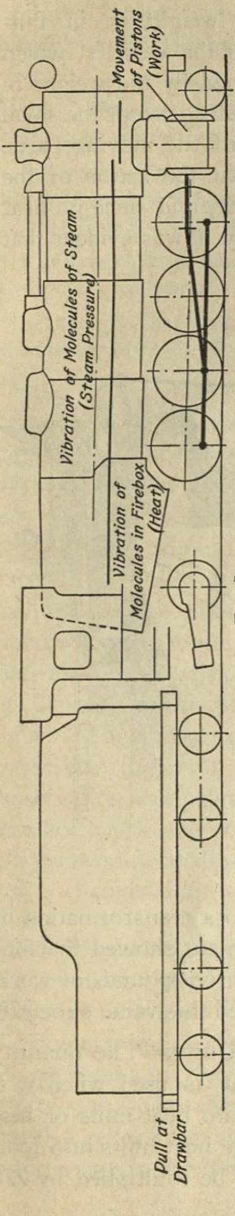

Movement of Pistons (Work)
Vibration of Molecules of Steam (Steam Pressure)
Vibration of Molecules in Firebox (Heat)
Pull at Drawbar

Fig. 7

The steam locomotive is then a heat engine, or an engine in which heat is converted into work through the medium of water.

**26.** A definite relation has been established between the unit of heat, or British thermal unit, and the unit of work, or the foot-pound. Experiments have shown that one British thermal unit is equivalent of 778 foot-pounds of work. This means that the increase in the vibrations of the molecules of 1 pound of water when raised from 62° F. to 63° F., if wholly converted into work, would raise 1 pound 778 feet high or 778 pounds 1 foot high. The quantity 778 is called the mechanical equivalent of heat.

The first experiment to determine with a fair degree of accuracy the relationship between heat and work was performed by Joule. By means of the apparatus shown in Fig. 8 he found that one pound of water was increased in temperature one degree by the work done during the descent of 772 pounds one foot. By an arrangement of drums and pulleys, the weight $w$, in falling, was made to operate the paddles $p$ in the vessel $v$, which was filled with water. The work performed by the weight in falling was all expended in churning the water, except the small quantity used in overcoming the friction of the moving parts. A very delicate thermometer $t$ showed that the action of the paddles raised the temperature of the water, and since no heat was applied to the water in any other way it was evident that the rise in temperature was due directly to a transformation of work into heat. Although Joule's experiment showed that one British thermal unit was equivalent to 772 foot-pounds of work, later and more accurate experiments showed this value to be 778.

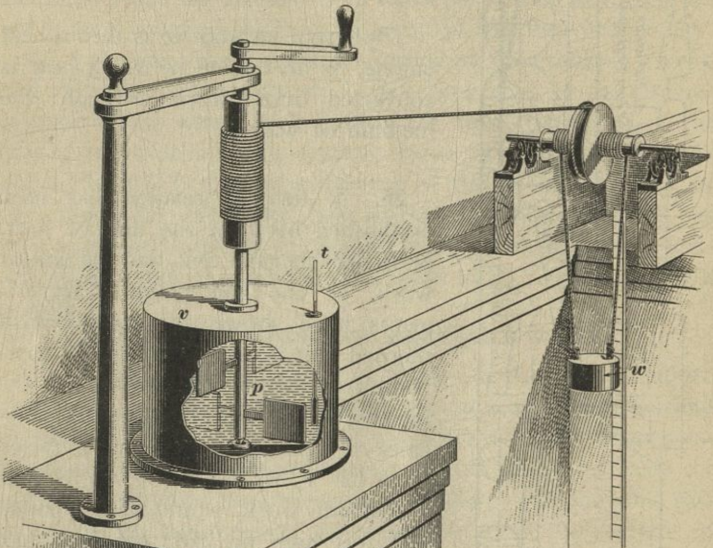


Fig. 8

**27. Conversion of Heat and Work Units.**—The quantity 778, or the mechanical equivalent of heat, is used when it is desired to change foot-pounds of work into heat units or heat units into foot-pounds of work. To change heat units into foot-pounds, the number of heat units should be multiplied by 778 and to change foot-pounds into heat units, the foot-pounds should be divided by 778.

Example.—A pound of a certain coal has a heating value of 12,500 B. t. u. How many foot-pounds of work would be performed if it were possible to convert all of this heat into work?

Solution.—The number of ft.-lb. of work can be found by multiplying the total number of heat units by the mechanical equivalent of heat; thus, 12,500×778=9,725,000 ft.-lb. Ans.

Example.—What equivalent amount of heat is represented by 266,067 foot-pounds of work?

Solution.—The number of heat units can be determined by dividing the number of ft.-lb. of work by 778; thus, 266,076÷778=342 B. t. u.

It is important for a fireman to know the relation between heat and work because he will then realize more fully the importance of skilful firing. As the heat developed by the burning of the fuel in the firebox ultimately appears as a pull at the drawbar, or as work, the cost at which the work is being done will depend on the amount of heat evolved from each pound of coal burned. If the firing is done carelessly, large amounts of the coal will escape unburned or it may merely burn to carbon monoxide and, while the locomotive may be performing the same amount of work as if the firing were being done skillfully, yet the cost of the work in the former instance will be much higher. The amount of coal used over and above that necessary to perform the work represents waste. The purpose of fuel-conservation campaigns on railroads is to stress the fact that heat and work are convertible and that the cost of the work will decrease according as more of the heat in each scoopful of coal is changed into work by skilled firing.

28. **Machines for Changing Heat Into Work.**—With steam as a medium, there are only two methods whereby heat can be converted into work: (1) by means of a suitable arrangement of cylinders and pistons as with the reciprocating steam engine; (2) by means of the steam turbine.

With the steam engine, the vibration of the molecules, or the heat that occurs during the burning of the fuel, is communicated to the water in the boiler and results in a vibration of the molecules of the water. The vibration of the water molecules increases until finally the attraction that holds them together is overcome to such an extent that some of them are expelled from the liquid at a high velocity. These rapidly moving molecules of water are called *steam.*

The continual bombardment of the interior of the boiler by the countless number of steam molecules that are finally expelled as the water continues to be heated, causes a thrust against the sheets; that is, the sheets will have an outward pressure acting upon them.

When the throttle is opened, the pressure exerted by the heat, or the vibration of the steam molecules in the boiler, will be transferred to the cylinders as well, and will move the pistons. The locomotive will then move and exert, through its drawbar, a pull on the train. The movement of the pistons should not be ascribed to the pressure of the steam but to the heat, or the vibration of the molecules of the steam that causes the pressure.

The vibration of the molecules that accompanies the burning of the fuel in the firebox is called heat, and the movement of the train by the locomotive is known as work. It is clear, therefore, that the heat generated by the burning fuel is finally converted into work at the drawbar.

The steam turbine, unlike the reciprocating engine with its arrangement of cylinders and pistons, converts heat into work in a different manner. This type of engine uses a series of steam nozzles for this purpose. Owing to its compact design and great economy, the turbine engine is in almost universal use in large power plants.

**29.** The arrangement of the cylinder and piston causes heat to be converted into work because the cylinder confines the steam molecules and causes their vibration to be imparted to the piston, thereby causing it to move. The steam nozzle is an extremely ingenious device because it accomplishes the transformation of heat into work without the use of any moving parts whatever. This device converts heat into work by changing heat, or the random and aimless movement of the steam molecules, into a definite movement in one direction at a high velocity.

The velocity of the steam is increased about eight times. This stream of molecules will develop a high pressure when directed against the blades of a turbine wheel, and will cause it to revolve. Therefore, the steam nozzle converts heat into work because it causes the steam molecules to travel faster.

The tube is so shaped that it diverges or widens toward the outlet. Such a construction causes a gradual expansion of the steam with a corresponding reduction in its temperature, or in the vibration (or to-and-fro motion) of its molecules and in an increase in their velocity, or their movement in a straight line, forward.

This may be more easily understood by considering the tube as being divided into a great number of zones, *a*, *b*, *c*, etc., Fig. 9, in which, owing to their gradually increasing cross-sectional area, the temperature, and consequently the pressure, of the steam are progressively lowered toward the outlet. This results in the steam particles passing from zone to zone at an ever increasing velocity. It can be seen, therefore, that the nozzle gradually transforms the vibration of the steam particles, that is, transforms the heat into a forward movement of the steam particles at a high velocity, or into work.

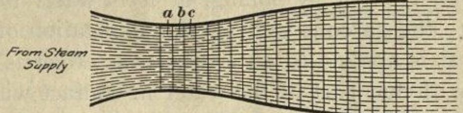


Fig. 9

The steam nozzle of an injector is similar to the steam nozzle of a turbine; the high velocity of the steam is imparted to the water in the combining tube but, owing to the low pressure of the steam, the water exerts little pressure against the sides of the tube. The required water pressure is obtained by reducing the velocity of the water by the delivery tube. The pressure of the water is then raised high enough to open the boiler check-valve.

**30.** With the gasoline engine, an arrangement of cylinders and pistons is used; the transformation of heat into work is accomplished by heating or setting into rapid vibration the molecules of gases by the combustion of gasoline vapor in the cylinders. A small quantity of gasoline vapor mixed with the correct amount of air to insure proper combustion is drawn into a cylinder during one stroke of the piston. On the return stroke, the mixture is compressed and is then ignited by a spark. The combustion that results occurs so quickly that it is termed an explosion, and the gases generated are very hot, or their molecules are in intense vibration, hence they exert a high pressure on the piston.

Owing to the compression of the mixture prior to combustion, the paths of the particles after combustion are shortened; therefore the pressure obtained is higher than otherwise.

## STEAM

31. **Definition.**—Steam is molecules of water that have been expelled from it by boiling, or it is water that has been changed into the gaseous state by the application of heat.

When heat is applied to water, the first effect is to raise the temperature of that part of the water in contact with the vessel in which it is being heated. The heated water then rises and the cooler water descends to take its place. The circulation thus set up causes the whole body of water to become heated and the rate of vibration of the molecules will increase as the temperature rises. Finally, a point is reached at which the vibration of the molecules becomes so great that some of them fly up into space above the surface of the water. The point at which this occurs is called the boiling point, and the molecules of water that are expelled are called steam.

It is of interest to note that the three different states in which water exists are due to the rate of vibration of its molecules. With water in the form of steam, the molecules are in rapid vibration and hence are widely separated. With a lesser rate of vibration, the molecules are less widely separated and they form a liquid; and with a still lesser rate of vibration, the molecules are in such intimate contact that a solid, or ice, is formed.

32. **Theory of Steam Pressure.**—The theory of steam pressure has already been given to some extent in Art. 31, and little

further explanation is necessary. When water is heated in a confined space like a locomotive boiler, the expulsion of the steam molecules from the water will continue until at last the space above the water is filled with countless particles that strike, and hence exert a pressure against, the interior of the boiler and also on the surface of the water. This condition is shown in Fig. 10, in which the steam molecules are indicated by black dots and their paths by dotted lines. Steam pressure is thus seen to be the result of the incessant movement of innumerable molecules of steam.

The gradual increase that occurs in the steam pressure as the water in the boiler continues to be heated is explained as follows: The molecules of steam, as they strike against and exert a pressure on the interior of the boiler, also return and strike against and exert a pressure on the surface of the water. The result is that, before any new molecules can be expelled from the water, their vibration must be increased, or the temperature of the water must be increased; hence, when they finally leave the water as steam, their velocity and the pressure they will exert will be greater. The increase in pressure will again make the expulsion of the steam particles from the water more difficult, and when they are expelled they in turn will exert a greater pressure. The result will be a gradual increase in the steam pressure as the water continues to be heated, until the pressure increases to that at which the safety valve is set. The ordinary boiler pressure in locomotive practice is 200 pounds, hence the vibration of the molecules of steam is great enough to exert a pressure of 200 pounds on each square inch of the interior of the boiler.

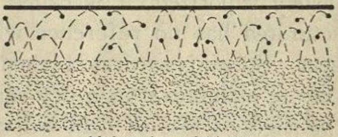


FIG. 10

**33.** For every pressure, there is a definite temperature at which water will boil. This is to be expected because, as the pressure on the water increases, the temperature, or the rate of vibration of the molecules of the water, must be increased before other molecules can be expelled. The relation between temperature and pressure as well as other data relating to steam is found in the steam tables.

Under atmospheric pressure, or 14.7 pounds per square inch, water will boil or change into steam when its temperature reaches 212° F. At 200 pounds gauge pressure, the boiling temperature of water is about 388° F.

34. **Saturated Steam.**—Saturated steam is steam that is in direct contact with the water from which it was formed, and it has the same temperature as the water. Thus, the steam in a locomotive boiler is saturated steam, but this does not mean that it is necessarily wet steam. If the water in a boiler is dirty, or if the boiling is very violent, particles of water may be cast up into the steam and be held in it as a sort of mist or spray. Such steam is called wet saturated steam. But if the steam is free from all trace of moisture, or, in other words, if it is completely vaporized, it is called dry saturated steam. The term saturated has no reference whatever to moisture; it refers to heat. Steam is saturated when it has taken up all the heat necessary to maintain it as a dry vapor. It is in such a condition that the slightest loss of heat will cause a part of the steam to condense.

35. **Superheated Steam.**—So long as the steam in a boiler is in close communication with the water, the steam cannot be otherwise than saturated. Any attempt to heat the steam to a higher temperature will merely cause more water to be evaporated. To increase the temperature of the steam, it must be removed from the presence of water, and more heat added to it. Steam that has been heated after it has been removed from contact with water is called superheated steam. A device used to superheat steam is called a superheater.

36. **Degree of Superheat.**—The difference between the temperature of superheated steam and saturated steam with both at the same pressure, is known as the degree of superheat. Thus, at 200 pounds gauge pressure, the temperature of saturated steam is 388° F. and, at the same pressure when superheated, the temperature of the steam may be 588° F. The degree of superheat is the difference between 588° and 388° F., or 200° F.

**37. Temperature and Pressure.**—Owing to the additional heat that has been imparted to superheated steam, its molecules vibrate much more rapidly than the molecules of saturated steam. As the pressure of the steam is dependent on the rate of vibration of its molecules, it would be natural to assume that steam when superheated would be at a higher pressure than when in the saturated state. This may or may not be the case and will depend on the manner in which the superheating is done.

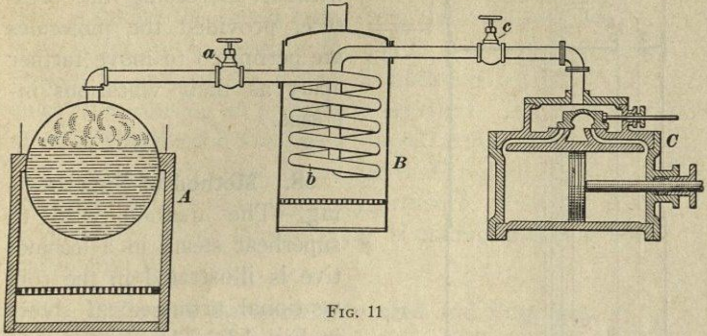


FIG. 11

In Fig. 11, if the steam from the boiler *A* is permitted to enter the coil *b*, and if the cocks *a* and *c* are then closed, the heat in the drum *B* will increase the rate of vibration of the molecules, hence the pressure exerted by them will increase. However, if steam is permitted to enter the bottom of a chamber *a*, Fig. 12, and if, as the steam is heated, the piston *b* is raised up a little at a time so as to allow the molecules of steam to occupy more space as their vibrations are increased by being heated, the result will be different. If the piston is raised at the proper rate, the pressure will remain constant, because, although the molecules are vibrating faster, they are now free to move farther apart, thereby losing velocity, and as a result they strike no harder against the walls of the chamber.

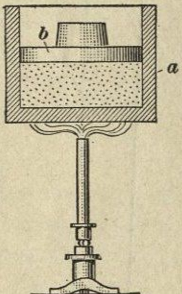


FIG. 12

Therefore, it is possible to superheat steam and increase the vibrations of its molecules without increasing the pressure, provided the molecules are permitted to move farther apart as their vibrations increase.

**38. Method of Superheating.**—The method used to superheat steam in a locomotive is illustrated in the conventional arrangement shown in Fig. 13. The steam passes from the boiler, through the dry pipe *a* to the compartment *b* in the superheater header *c*. Next the steam passes through the superheater units *d*, one shown, within the large flue *e*, to the compartment *f* in the superheater header. From the compartment *f*, the steam passes to the steam chests through the steam pipes *g*, one shown. The hot gases that are passing from the firebox *h* to the smokebox through the flue *e*, impart heat to the steam in the superheater unit and the molecules of steam receive additional vibration. With an actual superheater header, there are a large number of compartments *b* and *f* and hence a large number of units *d*.

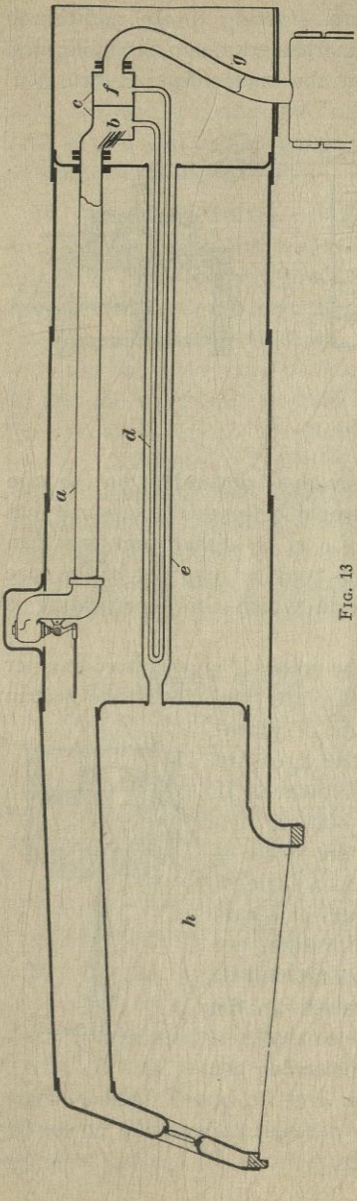


Fig. 13

The pressure of the steam in the superheater unit *d* does not increase, even though the molecules of steam are vibrating more rapidly than in the boiler. The reason is that the almost constant passage of steam to the steam chest with the locomotive in operation, is taking the steam away from the unit, and this gives the same effect on the steam in the coil as if it were being enlarged enough to prevent the increased vibration of the steam molecules from causing an increase in pressure. In other words, the molecules in the coil are free to move farther apart in the direction of the steam chest, hence increased vibration of the molecules does not result in increased pressure. Therefore, the condition under which superheating is taking place is similar to that in Fig. 12.

**39. Difference Between Saturated and Superheated Steam.** The important difference between saturated and superheated steam is that, with saturated steam, the force with which the steam molecules are expelled from the liquid exceeds only slightly the force of attraction between the molecules. A slight decrease in the velocity of the steam molecules causes the force of attraction to pull and hold them together and thereby form water, or the steam condenses. The loss of steam through the condensation of saturated steam runs as high as 30 per cent.

On the other hand, the molecules of superheated steam are in more rapid motion and the force of attraction between the molecules will not act to bring them together and form water until their rate of movement is slightly less than that of saturated steam at the same pressure. Therefore, the increased rate of vibration of the molecules of superheated steam delays condensation.

**40. Advantages of Superheating Steam.**—Briefly, the advantage of superheating steam is that the same effect is obtained as if the capacity of the boiler for generating steam was increased. This is explained as follows: The steam that was formerly lost by condensation is now saved, and this is equivalent to a corresponding increase in the capacity of the boiler to generate steam. A greater steam-generating capacity means that a higher cylinder pressure with an accompanying greater drawbar pull can be maintained at higher speeds. In other words, the engine steams more freely than otherwise and the steam is generated fast enough to maintain the pressure in the cylinders nearer to the working pressure at higher speeds.

**41. High-Temperature Steam.**—As heat can be converted into work, it follows that, as the temperature of the steam is increased, more heat becomes available for the performance of work. However, any increase in the temperature of the steam above that ordinarily used in locomotive service is obtained only at the expense of an abnormal increase in pressure. For example, to obtain an increase of 18° F. with the pressure already at 200 pounds will result in an increase in pressure of 50 pounds, and to obtain an increase in temperature of 19° F. with the pressure at 250 pounds requires an increase in pressure to 310 pounds. Thus, the increase in pressure is not proportional; the pressure increases more rapidly than the temperature.

With the boiler pressure somewhat in excess of 250 pounds, the water-tube firebox must be resorted to because the ordinary box type of firebox cannot be stayed to withstand high pressures. The principal objection to the water-tube firebox, unless the feed-water is pure, is the difficulty experienced and the time consumed in keeping the water tubes free from scale.

**42. Utilization of High-Temperature Steam.**—The amount of work obtained from heat in a locomotive depends on the difference between the temperature of the steam at admission to the cylinder and its temperature at exhaust. Therefore, the efficient use of high-temperature steam or of high-pressure steam, if this latter phrase is preferred, is a matter of using the steam expansively and thereby obtaining a low exhaust-steam temperature. The required expansion cannot be obtained with the conventional locomotive, as it is of the single-expansion type, and some system whereby the steam would be expanded twice, such as compounding, would have to be resorted to, in order to use the steam economically. Therefore, while theoretically the use of high-temperature steam is advantageous, yet its application to locomotive practice offers difficulties due to the radical changes required in the design of the boiler and engine.

With boiler pressures around 250 pounds per square inch, a certain degree of expansion can be secured by an increase in the steam lap. However, a wide steam lap requires a long valve travel if a late maximum cut-off is to be obtained; the travel that can be secured with the ordinary valve gear is limited.

A wide steam lap can be obtained by sacrificing a late maximum cut-off. Thus, a considerable number of locomotives have been constructed with the maximum cut-off limited to 50 or 60 per cent., starting ports being employed to supplement the steam ports when lifting trains. The wide steam lap insures adequate expansion of the steam. The term limited cut-off is applied to this type of locomotive.

**43. Increasing the Drawbar Horsepower.**—Any device that causes the heat of the burning fuel in the firebox to be utilized more fully in the generation of steam serves to increase the capacity of the boiler to generate steam and thereby increases the drawbar horsepower. Such devices include the superheater, arch tubes, thermic siphons, brick arches, combustion chambers, feed-water heaters, and exhaust-steam injectors. All these devices serve to increase the capacity of the boiler to make steam without any increase in the quantity of fuel burned.

The superheater uses the heat of the gases from the firebox to heat the steam on its passage to the cylinders, thus saving steam by preventing condensation. Any saving in steam is equivalent to an increase in the capacity of the boiler to make steam, by the amount saved.

**44.** Arch tubes and thermic siphons speed up the circulation of the water in the boiler, thereby permitting the water to absorb the heat more rapidly and thus increase the rate at which steam is being generated.

The brick arch is a mixing device that serves to mix the gases of combustion with the oxygen of the air. An excess of oxygen above the fuel bed does not imply a complete combustion of the gases; they must be intimately mixed with the oxygen and given time to burn.

The combustion chamber provides a space for the combustion of the gases, sparks, and cinders that may leave the firebox unburned. Therefore, the brick arch and the combustion chamber cause the heat of the burning fuel to be more fully utilized in the generation of steam.

The feed-water heater reclaims heat that otherwise would be wasted by using the heat of the gases from the firebox to heat the feed-water before it enters the boiler. This action increases the rate at which the steam is generated because the feed-water, being already heated, can be more quickly turned into steam.

**45.** The exhaust-steam injector is operated by exhaust steam; hence, the steam ordinarily taken from the boiler to operate the injector is saved, and this is the same as if the capacity of the boiler to generate steam were increased by the amount of steam saved.

Sometimes the size of the firebox is increased so as to keep the rate of combustion within more reasonable limits, thereby giving a higher firebox temperature and an increase in the steam-generating capacity. Fireboxes of this size are usually carried on four-wheel trailing trucks.

It should be remembered that all devices that serve to increase the steam-generating capacity of the boiler also serve to keep the size of the boiler within reasonable limits. A locomotive boiler that would generate steam at the same rate as a modern boiler equipped with the devices just mentioned would have to be made of such a size as to be impracticable.

## STEAM TABLES

### PROPERTIES OF SATURATED STEAM

**46.** Saturated steam possesses a number of properties that change as the pressure on the steam is changed. These properties are as follows: (1) the temperature of the steam; (2) the heat of the liquid; (3) the latent heat of vaporization, usually called latent heat; (4) the total heat of vaporization, or the total heat; (5) the volume of the steam; (6) the weight of the steam.

The foregoing properties have been determined by experiment and arranged in tables called Steam Tables. See Table I. The quantities given in the steam table are for one pound of water or steam; therefore, to find the heat of the liquid, the latent heat, or the total heat of a greater weight of water or steam, it is necessary to multiply the quantity given in the steam table by the weight of the water or the steam that is being considered.

## EXPLANATION OF SATURATED-STEAM TABLE

**47. Pressure.**—All of the properties of saturated steam depend on the absolute pressure under which it is formed; hence, in the steam table, pressure is the first item given. The pressure offers a resistance to the expulsion of the steam particles from the water and the amount of this resistance determines the other properties of the steam.

For example, if water boils under atmospheric pressure, or 14.7 pounds per square inch, the temperature of the water and the steam is 212° F., the heat of the liquid, if one pound is considered, is 180 B. t. u., the latent heat is 971.7 B. t. u., and the total heat is 1151.7 B. t. u.

On the other hand, if the pressure is 50 pounds absolute, the temperature of the water and the steam will be 281° F., the heat of the liquid will be 249.8 heat units, the latent heat 925.9 heat units, and the total heat 1175.6 heat units.

It will be noted that absolute pressures are used in the steam table; that is, the pressure is reckoned from the point of vacuum, or no pressure. Absolute pressure is the weight of the atmosphere, or 14.7 pounds per square inch, greater than gauge pressure; that is, when the gauge registers no pressure, the corresponding absolute pressure is 14.7 pounds. Therefore, 14.7 pounds must be added to a gauge pressure before it can be used with this table.

**48. Temperature of Evaporation.**—The second column of the steam table gives the temperatures at which water will boil when under the absolute pressures given in the first column. The temperature of the steam generated will be the same as the temperature of the water. The steam table shows that the boiling temperature increases as the pressure increases, and decreases as the pressure decreases. At atmospheric pressure, or 14.7 pounds per square inch, the boiling temperature is 212° F.; at

## TABLE I

### PROPERTIES OF SATURATED STEAM

(Compiled from Prof. G. A. Goodenough's Steam Table and printed with his permission and that of the publisher, John Wiley & Sons, Inc.)

| Absolute Pressure Pounds per Sq. In. *p* | Temperature Degrees F. *t* | Heat of the Liquid B. t. u. *q* | Latent Heat of Vaporization B. t. u. *l* | Total Heat B. t. u. *h* | Volume per Pound Cubic Feet *v* | Weight per Cubic Foot Pounds *w* |
|---|---|---|---|---|---|---|
| 1 | 101.76 | 69.76 | 1035.6 | 1105.4 | 333.3 | .00300 |
| 2 | 126.10 | 94.02 | 1022.2 | 1116.2 | 173.6 | .00576 |
| 3 | 141.49 | 109.38 | 1013.5 | 1122.9 | 118.7 | .00843 |
| 4 | 152.99 | 120.9 | 1007.0 | 1127.9 | 90.6 | .01104 |
| 5 | 162.25 | 130.1 | 1001.6 | 1131.7 | 73.5 | .01360 |
| 6 | 170.07 | 137.9 | 997.1 | 1135.0 | 62.0 | .01614 |
| 7 | 176.85 | 144.7 | 993.1 | 1137.8 | 53.7 | .01864 |
| 8 | 182.87 | 150.8 | 989.5 | 1140.3 | 47.35 | .02112 |
| 9 | 188.28 | 156.2 | 986.3 | 1142.5 | 42.41 | .02358 |
| 10 | 193.21 | 161.1 | 983.3 | 1144.4 | 38.43 | .02602 |
| 11 | 197.75 | 165.7 | 980.5 | 1146.2 | 35.16 | .02844 |
| 12 | 201.96 | 169.9 | 978.0 | 1147.9 | 32.41 | .03086 |
| 13 | 205.88 | 173.8 | 975.6 | 1149.4 | 30.07 | .03326 |
| 14 | 209.56 | 177.5 | 973.3 | 1150.8 | 28.06 | .03564 |
| 14.7 | 212 | 180.0 | 971.7 | 1151.7 | 26.81 | .03730 |
| 15 | 213.0 | 181.0 | 971.2 | 1152.2 | 26.30 | .03802 |
| 16 | 216.3 | 184.3 | 969.1 | 1153.4 | 24.76 | .04038 |
| 18 | 222.4 | 190.5 | 965.2 | 1155.7 | 22.18 | .04508 |
| 20 | 228.0 | 196.0 | 961.7 | 1157.7 | 20.10 | .0498 |
| 22 | 233.1 | 201.2 | 958.4 | 1159.6 | 18.38 | .0544 |
| 24 | 237.8 | 206.0 | 955.3 | 1161.3 | 16.95 | .0590 |
| 26 | 242.2 | 210.4 | 952.4 | 1162.8 | 15.73 | .0636 |
| 28 | 246.4 | 214.6 | 949.7 | 1164.3 | 14.67 | .0681 |
| 30 | 250.3 | 218.6 | 947.1 | 1165.7 | 13.76 | .0727 |
| 32 | 254.0 | 222.4 | 944.6 | 1166.9 | 12.95 | .0772 |
| 34 | 257.6 | 225.9 | 942.2 | 1168.1 | 12.24 | .0818 |
| 36 | 260.9 | 229.4 | 939.9 | 1169.2 | 11.60 | .0862 |
| 38 | 264.2 | 232.6 | 937.7 | 1170.3 | 11.03 | .0907 |
| 40 | 267.2 | 235.8 | 935.5 | 1171.3 | 10.51 | .0951 |
| 42 | 270.2 | 238.8 | 933.5 | 1172.2 | 10.04 | .0996 |
| 44 | 273.0 | 241.7 | 931.5 | 1173.2 | 9.61 | .1040 |
| 46 | 275.8 | 244.5 | 929.6 | 1174.0 | 9.22 | .1085 |
| 48 | 278.4 | 247.2 | 927.7 | 1174.8 | 8.86 | .1129 |
| 50 | 281.0 | 249.8 | 925.9 | 1175.6 | 8.53 | .1173 |

**TABLE I—Continued**

| Absolute Pressure Pounds per Sq. In. $p$ | Temperature Degrees F. $t$ | Heat of the Liquid B. t. u. $q$ | Latent Heat of Vaporization B. t. u. $l$ | Total Heat B. t. u. $h$ | Volume per Pound Cubic Feet $v$ | Weight per Cubic Foot Pounds $w$ |
|---|---|---|---|---|---|---|
| 52 | 283.5 | 252.3 | 924.1 | 1176.4 | 8.22 | .1217 |
| 54 | 285.9 | 254.7 | 922.4 | 1177.1 | 7.93 | .1261 |
| 56 | 288.2 | 257.1 | 920.7 | 1177.8 | 7.67 | .1304 |
| 58 | 290.5 | 259.5 | 919.0 | 1178.5 | 7.42 | .1348 |
| 60 | 292.7 | 261.7 | 917.4 | 1179.1 | 7.18 | .1392 |
| 62 | 294.9 | 263.9 | 915.8 | 1179.7 | 6.97 | .1435 |
| 64 | 296.9 | 266.1 | 914.3 | 1180.3 | 6.76 | .1479 |
| 66 | 299.0 | 268.2 | 912.7 | 1180.9 | 6.57 | .1522 |
| 68 | 301.0 | 270.2 | 911.2 | 1181.5 | 6.39 | .1566 |
| 70 | 302.9 | 272.2 | 909.8 | 1182.0 | 6.22 | .1609 |
| 72 | 304.8 | 274.2 | 908.3 | 1182.5 | 6.05 | .1652 |
| 74 | 306.7 | 276.1 | 906.9 | 1183.0 | 5.90 | .1695 |
| 76 | 308.5 | 278.0 | 905.5 | 1183.5 | 5.75 | .1738 |
| 78 | 310.3 | 279.8 | 904.2 | 1184.0 | 5.61 | .1781 |
| 80 | 312.0 | 281.6 | 902.8 | 1184.4 | 5.48 | .1824 |
| 82 | 313.7 | 283.4 | 901.5 | 1184.9 | 5.35 | .1868 |
| 84 | 315.4 | 285.1 | 900.2 | 1185.3 | 5.23 | .1910 |
| 86 | 317.1 | 286.8 | 898.9 | 1185.7 | 5.12 | .1953 |
| 88 | 318.7 | 288.5 | 897.7 | 1186.1 | 5.01 | .1996 |
| 90 | 320.3 | 290.1 | 896.4 | 1186.5 | 4.905 | .2039 |
| 92 | 321.8 | 291.7 | 895.2 | 1186.9 | 4.805 | .2081 |
| 94 | 323.3 | 293.3 | 894.0 | 1187.3 | 4.709 | .2124 |
| 96 | 324.8 | 294.8 | 892.8 | 1187.7 | 4.617 | .2166 |
| 98 | 326.3 | 296.4 | 891.6 | 1188.0 | 4.528 | .2209 |
| 100 | 327.8 | 297.9 | 890.5 | 1188.4 | 4.442 | .2251 |
| 102 | 329.2 | 299.4 | 889.3 | 1188.7 | 4.359 | .2294 |
| 104 | 330.7 | 300.9 | 888.2 | 1189.0 | 4.279 | .2337 |
| 106 | 332.0 | 302.3 | 887.1 | 1189.4 | 4.202 | .2380 |
| 108 | 333.4 | 303.7 | 885.9 | 1189.7 | 4.128 | .2422 |
| 110 | 334.8 | 305.1 | 884.8 | 1190.0 | 4.057 | .2465 |
| 112 | 336.1 | 306.5 | 883.7 | 1190.3 | 3.988 | .2508 |
| 114 | 337.4 | 307.9 | 882.7 | 1190.6 | 3.921 | .2550 |
| 116 | 338.7 | 309.2 | 881.6 | 1190.8 | 3.857 | .2593 |
| 118 | 340.0 | 310.6 | 880.6 | 1191.1 | 3.795 | .2635 |
| 120 | 341.3 | 311.9 | 879.5 | 1191.4 | 3.735 | .2678 |
| 122 | 342.5 | 313.2 | 878.5 | 1191.6 | 3.676 | .2720 |
| 124 | 343.7 | 314.4 | 877.5 | 1191.9 | 3.620 | .2762 |
| 126 | 345.0 | 315.7 | 876.4 | 1192.1 | 3.566 | .2805 |

### TABLE I—Continued

| Absolute Pressure Poundsper Sq. In. *p* | Tempera-ture Degrees F. *t* | Heat of the Liquid B. t. u. *q* | Latent Heat of Vaporiza-tion B. t. u. *l* | Total Heat B. t. u. *h* | Volume per Pound Cubic Feet *v* | Weight per Cubic Foot Pounds *w* |
|---|---|---|---|---|---|---|
| 128 | 346.2 | 316.9 | 875.4 | 1192.4 | 3.513 | .2847 |
| 130 | 347.4 | 318.2 | 874.4 | 1192.6 | 3.461 | .2889 |
| 132 | 348.5 | 319.4 | 873.5 | 1192.9 | 3.412 | .2931 |
| 134 | 349.7 | 320.6 | 872.5 | 1193.1 | 3.363 | .2973 |
| 136 | 350.8 | 321.8 | 871.5 | 1193.3 | 3.316 | .3016 |
| 138 | 352.0 | 323.0 | 870.5 | 1193.5 | 3.270 | .3058 |
| 140 | 353.1 | 324.2 | 869.6 | 1193.7 | 3.226 | .3100 |
| 142 | 354.2 | 325.3 | 868.6 | 1193.9 | 3.182 | .3142 |
| 144 | 355.3 | 326.5 | 867.7 | 1194.1 | 3,140 | .3184 |
| 146 | 356.3 | 327.6 | 866.8 | 1194.3 | 3.099 | .3227 |
| 148 | 357.4 | 328.7 | 865.8 | 1194.5 | 3.059 | .3269 |
| 150 | 358.5 | 329.8 | 864.9 | 1194.7 | 3.020 | .3311 |
| 155 | 361.1 | 332.5 | 862.7 | 1195.2 | 2.927 | .3417 |
| 160 | 363.6 | 335.2 | 860.5 | 1195.7 | 2.839 | .3522 |
| 165 | 366.1 | 337.8 | 858.3 | 1196.1 | 2.757 | .3627 |
| 170 | 368.5 | 340.3 | 856.2 | 1196.5 | 2.679 | .3733 |
| 175 | 370.8 | 342.8 | 854.1 | 1196.9 | 2.605 | .3838 |
| 180 | 373.1 | 345.2 | 852.0 | 1197.2 | 2.536 | .3943 |
| 185 | 375.4 | 347.6 | 849.9 | 1197.6 | 2,470 | .4048 |
| 190 | 377.6 | 350.0 | 847.9 | 1197.9 | 2.408 | .4154 |
| 195 | 379.7 | 352.2 | 846.0 | 1198.2 | 2.348 | .4259 |
| 200 | 381.9 | 354.5 | 844.0 | 1198.5 | 2.292 | .4364 |
| 205 | 383.9 | 356.7 | 842.1 | 1198.7 | 2.238 | .4469 |
| 210 | 386.0 | 358.8 | 840.2 | 1199.0 | 2.186 | .457 |
| 215 | 388.0 | 361.0 | 838.3 | 1199.2 | 2.137 | .468 |
| 220 | 390.0 | 363.0 | 836.5 | 1199.5 | 2.090 | .478 |
| 225 | 391.9 | 365.1 | 834.6 | 1199.7 | 2.045 | .489 |
| 230 | 393.8 | 367.1 | 832.8 | 1199.9 | 2.002 | .499 |
| 235 | 395.6 | 369.1 | 831.0 | 1200.1 | 1.961 | .510 |
| 240 | 397.5 | 371.0 | 829.3 | 1200.3 | 1.921 | .521 |
| 245 | 399.3 | 373.0 | 827.5 | 1200.5 | 1.883 | .531 |
| 250 | 401.1 | 374.9 | 825.8 | 1200.6 | 1.846 | .542 |
| 255 | 402.9 | 376.7 | 824.1 | 1200.8 | 1.811 | .552 |
| 260 | 404.5 | 378.6 | 822.4 | 1201.0 | 1.777 | .563 |
| 265 | 406.2 | 380.4 | 820.7 | 1201.1 | 1.745 | .573 |
| 270 | 407.9 | 382.2 | 819.1 | 1201.2 | 1.713 | .584 |
| 275 | 409.6 | 383.9 | 817.4 | 1201.4 | 1.683 | .594 |
| 280 | 411.2 | 385.7 | 815.8 | 1201.5 | 1.654 | .605 |

TABLE I—Continued

| Absolute Pressure Pounds per Sq. In. $p$ | Temperature Degrees F. $t$ | Heat of the Liquid B. t. u. $q$ | Latent Heat of Vaporization B. t. u. $l$ | Total Heat B. t. u. $h$ | Volume per Pound Cubic Feet $v$ | Weight per Cubic Foot Pounds $w$ |
|---|---|---|---|---|---|---|
| 285 | 412.8 | 387.4 | 814.2 | 1201.6 | 1.625 | .615 |
| 290 | 414.4 | 389.1 | 812.6 | 1201.7 | 1.598 | .626 |
| 295 | 415.9 | 390.8 | 811.0 | 1201.8 | 1.571 | .636 |
| 300 | 417.5 | 392.4 | 809.4 | 1201.9 | 1.545 | .647 |
| 310 | 420.5 | 395.7 | 806.4 | 1202.0 | 1.496 | .668 |
| 320 | 423.4 | 398.9 | 803.3 | 1202.2 | 1.450 | .690 |
| 330 | 426.3 | 402.0 | 800.3 | 1202.3 | 1.407 | .711 |
| 340 | 429.1 | 405.0 | 797.4 | 1202.4 | 1.366 | .732 |
| 350 | 431.9 | 408.0 | 794.5 | 1202.5 | 1.327 | .753 |
| 360 | 434.6 | 410.9 | 791.6 | 1202.5 | 1.291 | .775 |
| 370 | 437.2 | 413.7 | 788.8 | 1202.6 | 1.256 | .796 |
| 380 | 439.8 | 416.5 | 786.1 | 1202.6 | 1.223 | .817 |
| 390 | 442.3 | 419.3 | 783.3 | 1202.6 | 1.192 | .839 |
| 400 | 444.8 | 422.0 | 780.6 | 1202.5 | 1.162 | .860 |
| 410 | 447.2 | 424.6 | 777.9 | 1202.5 | 1.134 | .882 |
| 420 | 449.6 | 427.2 | 775.2 | 1202.4 | 1.107 | .903 |
| 430 | 451.9 | 429.8 | 772.6 | 1202.4 | 1.081 | .925 |
| 440 | 454.2 | 432.3 | 770.0 | 1202.3 | 1.056 | .947 |
| 450 | 456.5 | 434.8 | 767.4 | 1202.2 | 1.033 | .968 |
| 460 | 458.7 | 437.2 | 764.9 | 1202.1 | 1.010 | .990 |
| 470 | 460.9 | 439.6 | 762.4 | 1202.0 | .988 | 1.012 |
| 480 | 463.1 | 442.0 | 759.9 | 1201.9 | .968 | 1.033 |
| 490 | 465.2 | 444.3 | 757.5 | 1201.8 | .948 | 1.055 |
| 500 | 467.2 | 446.6 | 755.0 | 1201.7 | .928 | 1.077 |

5 pounds, absolute, the temperature is 162.25; whereas, at 100 pounds, absolute, or a gauge pressure of 85 pounds, the boiling temperature is 327.8° F. The foregoing is explained by the fact that, as the pressure on the water is increased, a higher temperature, or a greater vibration of the water molecules, is required before the molecules can overcome the pressure and be expelled as steam. The reverse will hold true as the pressure is decreased. Therefore, there is a different boiling temperature for each pressure.

49. **Heat of the Liquid.**—The heat of the liquid is the quantity of heat as measured in heat units that must be added

to water to raise its temperature from 32° F., or the freezing point, to the boiling temperature. It has already been explained that the boiling temperature varies with the pressure, hence there will be a different heat of the liquid for each different pressure. The heat of the liquid per pound of water is given for various pressures in the third column of the steam table.

One B. t. u. raises the temperature of 1 pound of water one degree, two B. t. u. raises the temperatures two degrees, and so on; hence the heat of the liquid will be equal, approximately, to the boiling temperature less 32°. Thus, the values in the third column of the steam table may be obtained approximately by subtracting 32 from the corresponding temperature in the second column. This method of calculating the heat of the liquid does not give exact results, because at some temperatures one B. t. u. will raise one pound of water more than one degree and at other temperatures less than one degree.

It must not be assumed that water at a temperature less than 32° F. contains no heat; actually, any substance above absolute zero contains some heat. The freezing point of water, or 32° F., is merely taken as a starting point in calculating the heat of the liquid. Therefore, the heat of the liquid as shown by the steam table is not all of the heat that the steam really contains, but merely the amount that has been added to a pound of water above 32° F.

**50. Latent Heat of Steam.**—The latent heat is the heat that must be added to water to convert it into steam after the boiling point has been reached.

After the water begins to boil, a large amount of heat must be applied to it to convert it completely into steam. A thermometer placed in the water after the boiling temperature is reached will show no increase in temperature; hence the heat that is being used in converting the water into steam is called latent heat. A great deal more heat is required to convert a pound of water into steam than is required to raise it to the boiling point. For example, at atmospheric pressure, as shown in the third column of the steam table, 180 B. t. u. is necessary to raise the temperature of one pound of water to the boiling point, whereas the fourth column shows that 971.7 B. t. u. is required to convert the pound of water completely into steam. The heat of the liquid is used to increase the temperature of the water, whereas the latent heat is used to break down the attraction of the molecules of water for each other and expel them as steam against the pressure existing on the surface of the water. The heat of the liquid increases with the pressure, the latent heat decreases with the pressure.

**51. Total Heat of Steam.**—The total heat of steam in B. t. u. is given in the fifth column of the steam table and is defined as all of the heat required to heat one pound of water from 32° F. to the boiling temperature and then change it into steam. The total heat of the steam is, then, the sum of the heat of the liquid and the latent heat, or it is the sum of columns three and four of the steam table.

The increase in the total heat of steam is small as the pressure increases; this is due to the fact that, although the heat of the liquid increases with the pressure, the latent heat decreases.

Although the gain in the total heat of one pound of steam in B. t. u. is small as the pressure is increased, yet the slight increase represents a considerable amount of work when the steam consumption of a locomotive is considered. The difference between the total heat of one pound of steam, Table II, at 250 pounds gauge pressure, superheated 200°, and a pound at 200 pounds pressure is $1315.6-1309.7$ or 5.9 B. t. u. Now the steam consumption of a locomotive per hour is about equal to the horsepower multiplied by 17.5, hence a locomotive of 2500 horsepower uses $2500\times17.5$ or 43,750 pounds of steam. An increase of 5.9 B. t. u. in the total heat of each pound of this steam represents a gain of $43750\times5.9$, or 258,125 B. t. u. available for the performance of work with the higher pressure.

**52. Volume Per Pound.**—The sixth column of the steam table gives the volume a pound of steam occupies for the different pressures. Thus, a pound of steam under 215 pounds absolute pressure, or about 200 pounds gauge pressure, occupies 2.137 cubic feet. The volume of the steam, of course, decreases with the pressure.

# TABLE II

## PROPERTIES OF SATURATED AND SUPERHEATED STEAM

| Absolute Pressure Pounds per Sq. In. | Saturated Steam | | Degrees of Superheat | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 200 | | 250 | | 300 | |
| | Temperature Degrees F. | Total Heat B. t. u. | Temperature Degrees F. | Total Heat B. t. u. | Temperature Degrees F. | Total Heat B. t. u. | Temperature Degrees F. | Total Heat B. t. u. |
| 200 | 381.9 | 1198.5 | 581.9 | 1307.7 | 631.9 | 1332.4 | 681.9 | 1357.0 |
| 205 | 383.9 | 1198.7 | 583.9 | 1308.3 | 633.9 | 1333.0 | 683.9 | 1357.7 |
| 210 | 386.0 | 1199.0 | 586.0 | 1309.0 | 636.0 | 1333.7 | 686.0 | 1358.4 |
| 215 | 388.0 | 1199.2 | 588.0 | 1309.7 | 638.0 | 1334.4 | 688.0 | 1359.1 |
| 220 | 390.0 | 1199.5 | 590.0 | 1310.3 | 640.0 | 1335.1 | 690.0 | 1359.8 |
| 225 | 391.9 | 1199.7 | 591.9 | 1310.9 | 641.9 | 1335.7 | 691.9 | 1360.3 |
| 230 | 393.8 | 1199.9 | 593.8 | 1311.6 | 643.8 | 1336.3 | 693.8 | 1361.0 |
| 235 | 395.6 | 1200.1 | 595.6 | 1312.2 | 645.6 | 1337.0 | 695.6 | 1361.7 |
| 240 | 397.5 | 1200.3 | 597.5 | 1312.8 | 647.5 | 1337.6 | 697.5 | 1362.3 |
| 245 | 399.3 | 1200.5 | 599.3 | 1313.3 | 649.3 | 1338.2 | 699.3 | 1362.9 |
| 250 | 401.1 | 1200.6 | 601.1 | 1313.9 | 651.1 | 1338.8 | 701.1 | 1363.5 |
| 255 | 402.9 | 1200.8 | 602.9 | 1314.5 | 652.9 | 1339.3 | 702.9 | 1364.1 |
| 260 | 404.5 | 1201.0 | 604.5 | 1315.1 | 654.5 | 1340.0 | 704.5 | 1364.7 |
| 265 | 406.2 | 1201.1 | 606.2 | 1315.6 | 656.2 | 1340.5 | 706.2 | 1365.3 |
| 270 | 407.9 | 1201.2 | 607.9 | 1316.2 | 657.9 | 1341.1 | 707.9 | 1365.9 |
| 275 | 409.6 | 1201.4 | 609.6 | 1316.7 | 659.6 | 1341.6 | 709.6 | 1366.5 |
| 280 | 411.2 | 1201.5 | 611.2 | 1317.2 | 661.2 | 1342.2 | 711.2 | 1367.0 |
| 285 | 412.8 | 1201.6 | 612.8 | 1317.8 | 662.8 | 1342.7 | 712.8 | 1367.5 |
| 290 | 414.4 | 1201.7 | 614.4 | 1318.3 | 664.4 | 1343.2 | 714.4 | 1368.0 |
| 295 | 415.9 | 1201.8 | 615.9 | 1318.8 | 665.9 | 1343.8 | 715.9 | 1368.7 |
| 300 | 417.5 | 1201.9 | 617.5 | 1319.3 | 667.5 | 1344.3 | 717.5 | 1369.2 |
| 305 | 419.0 | 1204.3 | 619.0 | 1319.8 | 669.0 | 1344.8 | 719.0 | 1369.7 |
| 310 | 420.5 | 1202.0 | 620.5 | 1320.3 | 670.5 | 1345.3 | 720.5 | 1370.2 |
| 320 | 423.4 | 1202.2 | 623.4 | 1321.3 | 673.4 | 1346.3 | 723.4 | 1371.3 |
| 330 | 426.3 | 1202.3 | 626.3 | 1322.2 | 676.3 | 1347.3 | 726.3 | 1372.3 |
| 340 | 429.1 | 1202.4 | 629.1 | 1323.2 | 679.1 | 1348.3 | 729.1 | 1373.3 |
| 350 | 431.9 | 1202.5 | 631.9 | 1324.1 | 681.9 | 1349.3 | 731.9 | 1374.3 |
| 360 | 434.6 | 1202.5 | 634.6 | 1325.0 | 684.6 | 1350.2 | 734.6 | 1375.3 |
| 370 | 437.2 | 1202.6 | 637.2 | 1325.9 | 687.2 | 1351.1 | 737.2 | 1365.9 |
| 380 | 439.8 | 1202.6 | 639.8 | 1326.8 | 689.8 | 1352.0 | 739.8 | 1377.1 |
| 390 | 442.3 | 1202.6 | 642.3 | 1327.7 | 692.3 | 1353.0 | 742.3 | 1378.1 |
| 400 | 444.8 | 1202.5 | 644.8 | 1328.6 | 694.8 | 1353.9 | 744.8 | 1379.1 |
| 425 | 450.8 | 1208.0 | 650.8 | 1331.0 | 700.8 | 1356.0 | 750.8 | 1381.0 |
| 450 | 456.5 | 1202.2 | 656.5 | 1333.0 | 706.5 | 1358.0 | 756.5 | 1383.0 |
| 475 | 462.1 | 1209.0 | 662.1 | 1335.0 | 712.1 | 1360.0 | 762.1 | 1385.0 |
| 500 | 467.2 | 1201.7 | 667.2 | 1337.0 | 717.2 | 1362.0 | 767.2 | 1388.0 |

**53. Weight per Cubic Foot.**—The seventh column of the steam table gives the weight of a cubic foot of steam under the different pressures. The weight increases with the pressure because a greater number of particles of steam will be contained in a cubic foot when the pressure is high than when low.

### SUPERHEATED STEAM TABLE

**54.** The second and third columns of Table II refer to saturated steam and are taken from Table I; the other columns of the table relate to steam that has been superheated to 200° F., 250° F., and 300° F.

The following example will explain how the table is to be used. At an absolute pressure of 200 pounds, water boils at a temperature of 381.9° F. and the total heat of one pound of water is 1198.5 B. t. u. If the steam is superheated 200° F. the temperature becomes 381.9 plus 200, or 581.9° F.; the total heat of the steam is now 1307.7, or an increase of 1307.7 minus 1198.5, or 109.2 B. t. u. The total heat of the steam when superheated 250° F. and 300° F. is 1332.4 and 1357.0 B. t. u.; thus, the total heat increases with the superheat.

## LOCOMOTIVE SUPERHEATERS

### ELESCO TYPE A SUPERHEATER

**55. General Arrangement.**—The purpose of the locomotive superheater is to utilize the heat of the gases from the firebox to impart additional heat to the steam on its passage to the steam chests. As shown in Fig. 14, the Elesco type A superheater consists of a header *a* to which the dry pipe *b* and the steam pipes *c* are connected; the superheater units *d* that are connected to the header and extend back into the superheater flues *e*; and a damper *f* that is actuated by the damper mechanism *g*.

**56. Superheater Header.**—An exterior view of a through-bolt superheater header, turned bottom side up, is shown in Fig. 15. Its purpose is to distribute the steam from the dry pipe to the superheater units, and from the units to the steam

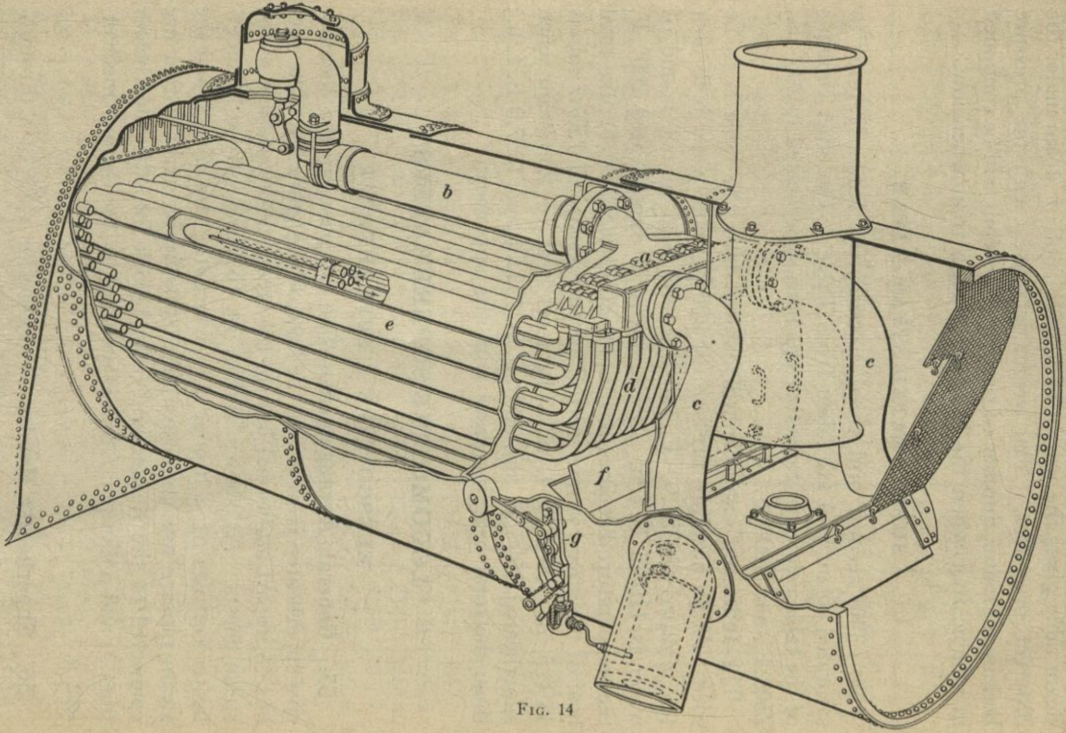


FIG. 14

pipes. The interior construction of the superheater header is given in Fig. 16, in which the top of the header is shown partly broken away. The header *a* contains a passageway *g* to which the compartments *j* connect, and a passageway *h* to which the compartments *i* connect. The passageway *g* communicates with the dry pipe, so that, with the locomotive in operation, the compartments *j* fill with saturated steam. The communication between the saturated-steam compartments and the compartments *i*, which are the superheated-steam compartments, is made by the superheater units, one shown. One end of a unit is connected to a circular opening in one compartment, and the other end is connected to a similar opening in an adjoining compartment. The superheater header is carried at the ends on header supports that are bolted to the smokebox. The heads of the unit bolts are shown at *l* and the slots in the header through which the bolts pass are indicated by *m*.

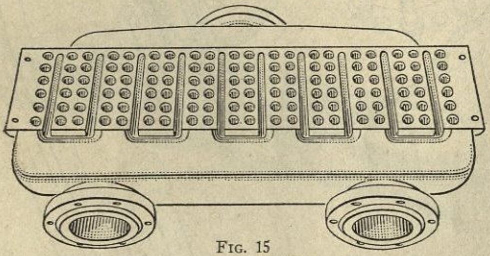


FIG. 15

**57. Superheater Units.**—The purpose of the superheater units, one of which is shown in Fig. 17, is to convey the saturated steam away from the saturated-steam compartments in the superheater header, and return it as superheated steam to the superheated-steam compartments in the header. The superheater units are placed within the superheater flues, and the heat of the firebox gases in passing through the flues is imparted to the steam in the superheater units, thereby superheating it.

Each superheater unit, in which the actual superheating is done, consists of four cold-drawn seamless steel tubes, carried as a cluster in each of the enlarged boiler flues that replace the standard 2-inch flues. The four sections of each unit are made

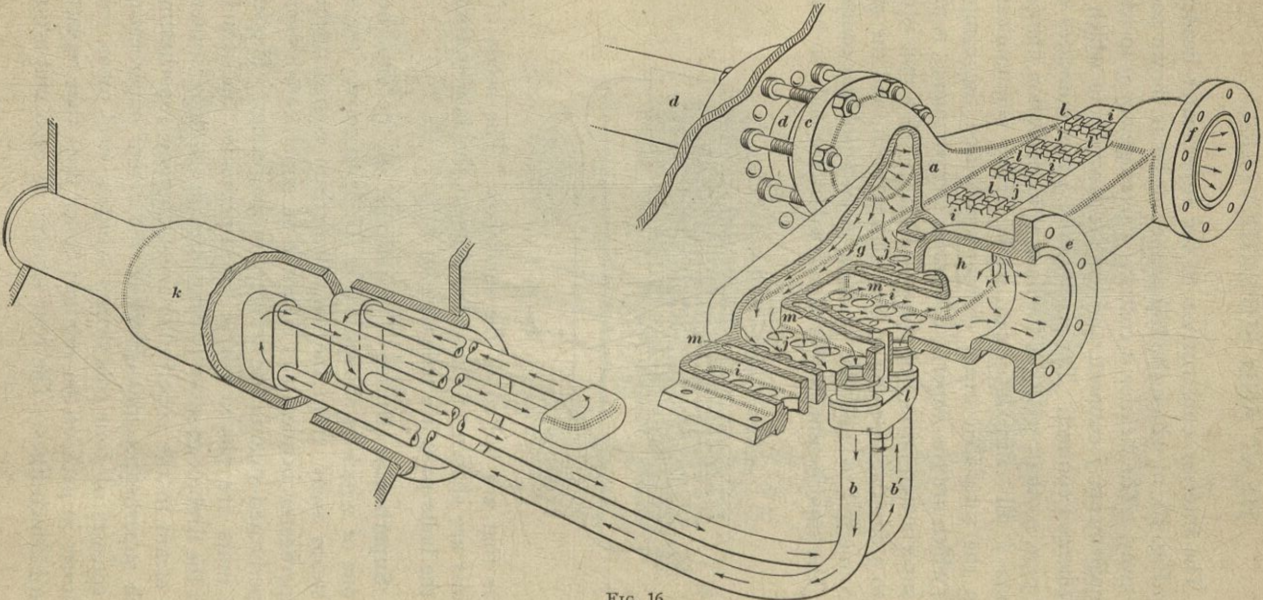


FIG. 16

into a continuous tube by forging the tube ends into a return bend in such a way as to permit a free flow of steam and also offer a minimum obstruction to the passage of hot gases through the flues. The return bends are forged integrally with the unit and from the same metal of which the unit itself is fabricated in a machine-forging operation, no oxy-acetylene or electric welding whatever being used. The steam enters the unit at one end *a*, Fig. 17, and leaves it at the other end *b*, passing through the unit as indicated by the arrows. The loops are doubled so as to increase the velocity at which the steam flows through the unit, in order to give a better degree of superheat, and also to protect the units from overheating.

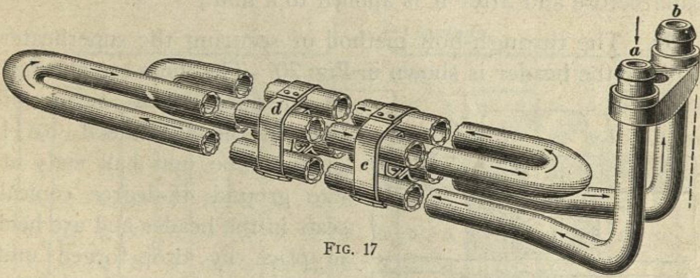


Fig. 17

The band *c* holds the pipes together and prevents them from moving. The support *d* is used for the same purpose, and in addition it has feet that hold the unit in the proper position in the superheater flue and also prevent the unit from vibrating in the flue.

**58.** The proper application of the bands and supports is very important. Any vibration of the unit in the flue will tend to break the joint between the unit pipe and the header and permit steam to escape into the smokebox. Also, if bands are used where supports should be used, the unit will rest on the flue, so that this part of the unit will not have the proper contact with the hot gases, and cinders and soot will have a greater opportunity to collect and block the flue. One band is required for each unit and is placed near the front, but the number of supports required depends on the length of the units, and they may number from one to four. Confusion sometimes exists as to the difference between a support and a band. The difference can be noted by considering Figs. 18 and 19. The former shows

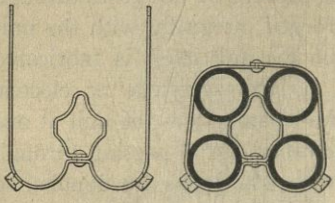

(a) (b)

Fig. 18

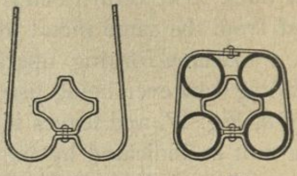

(a) (b)

Fig. 19

a support before and after application, and the latter shows a band before and after it is applied to a unit.

**59.** The through-bolt method of securing the superheater units to the header is shown in Fig. 20. The units are attached to the header by means of clamped metal-to-metal ball joints. The unit ball ends fit into ground 45-degree conical seats in the header and are held in place by drop-forged unit clamps *a* and bolts *b* of heat-treated steel. The illustration also shows the unit end washer *c*, the unit bolt washer *d*, and the unit bolt nut *e*.

The ball joint permits of quick and easy application or removal of the units without special tools. The joint is flexible, remains tight under the severest operating conditions, and is easy to adjust and maintain.

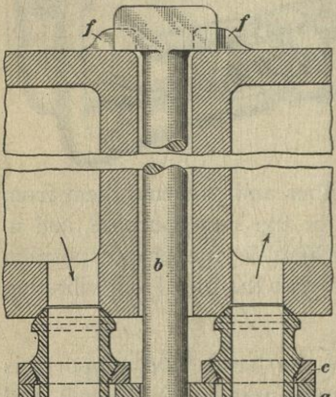


Fig. 20

The clamps and the washers for the ball joints are made of steel and the bolts are special heat-treated alloy steel with a minimum tensile strength of 100,000 pounds per square inch.

Slight variations in the shape of the units or in their application to the superheater flues, or other causes may prevent the units from being applied to the superheater header in exactly a vertical position. However, the head of the bolt *b* should make a bearing all around on the top of the header. The ball joints that the pipes make with the unit end washers *c*, as well as the ball joint that the bolt washer *d* makes with the clamp *a*, permit the unit to be applied slightly out of its true position, if necessary, without moving the bolt out of a vertical position. The ball-shaped ends of the units permit them to be moved slightly out of their vertical positions during application, if necessary, and still have the joints steam-tight. The unit clamp *a* and the unit end washer *c* are applied to the pipes before their free ends are forged together. The bolts *b* are passed up through the header from the bottom, then after being given one-quarter turn they are held from turning by the stops *f*.

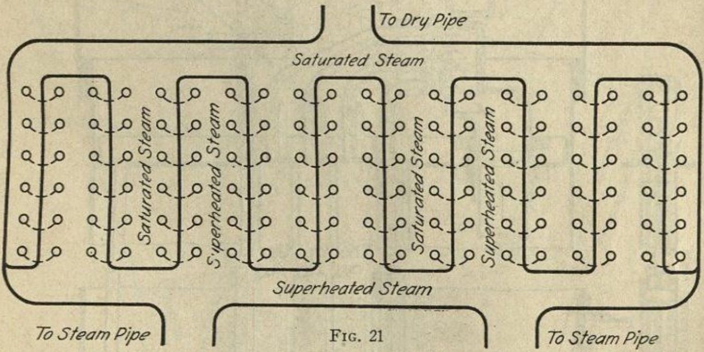


FIG. 21

**60. Arrangement of Units at Header.**—The conventional view in Fig. 21 shows the arrangement of the superheater units at the superheater header. It is assumed that the header is viewed from the top and that its upper portion is removed so as to show the interior. The units are connected to the holes in the bottom of the header, and the dash lines indicate the holes to which the two pipes of a superheater unit connect.

The saturated-steam compartments in the header, as well as the superheated-steam compartments, are indicated as such.

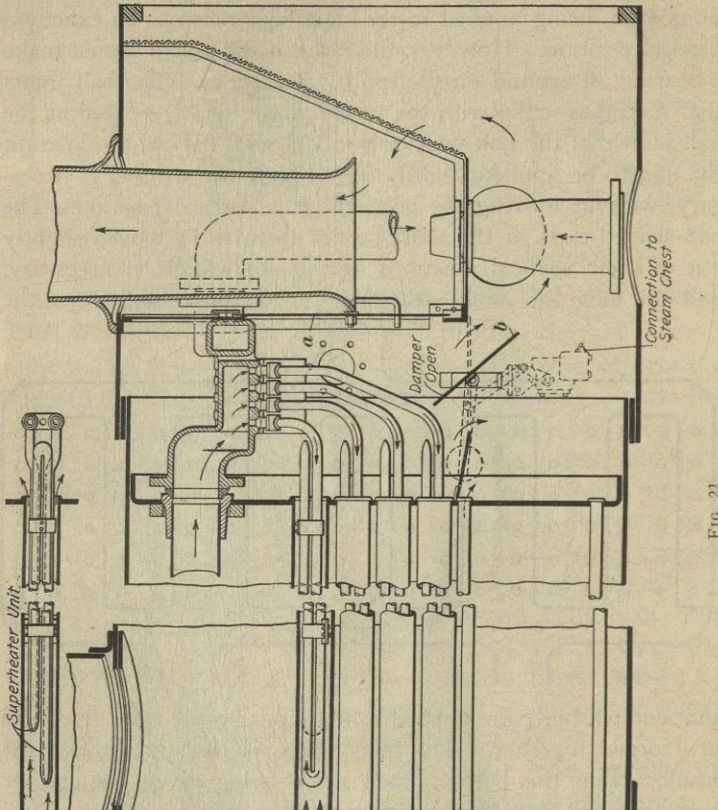


FIG. 21

The saturated steam passes from its compartments through the holes in those compartments to the inlet ends of the superheater units. The steam in its passage through the units is superheated and enters the superheated-steam compartments, from which it passes to the steam pipes. It will be noted that the two similarly located holes in each saturated- and superheated-steam compartment are connected by a superheater unit. There are 120 unit holes in the superheater, or 60 pairs; hence, 60 superheater units are required in piping the header.

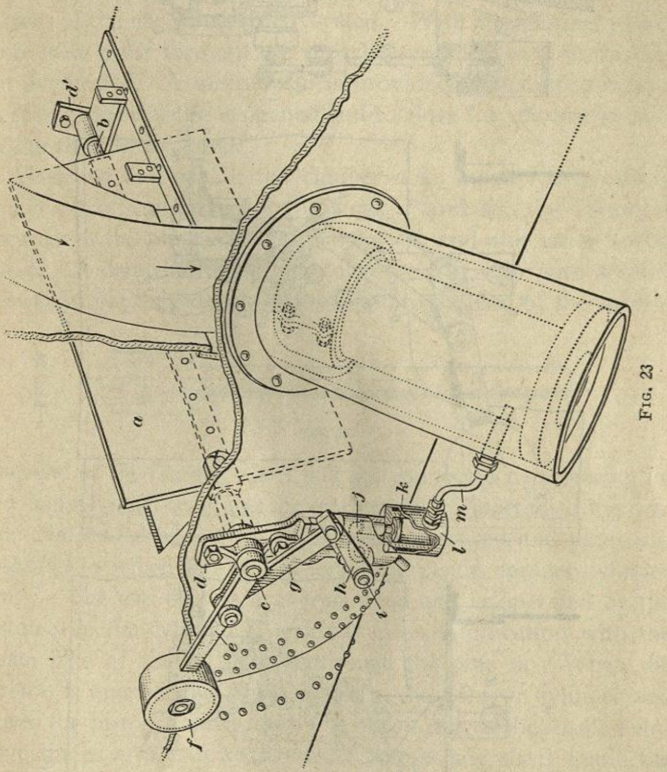
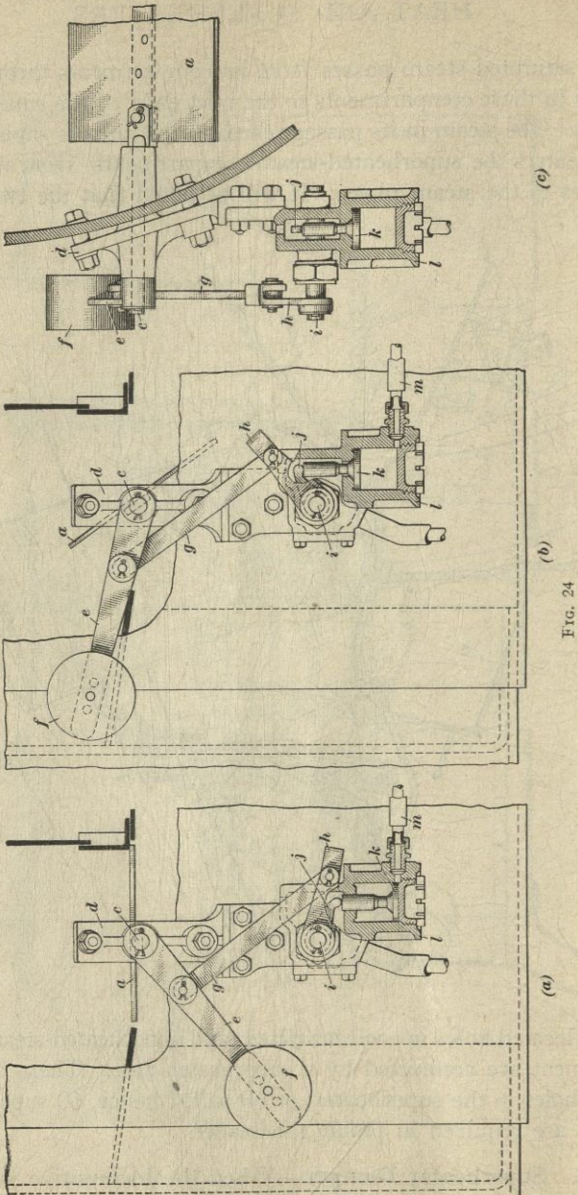


FIG. 23

**61. Superheater Damper.**—When the locomotive is working, the steam in the superheater units prevents them from



(a)

(b)

(c)

FIG. 24

being overheated by the firebox gases. There is no steam in the superheater units of the type A superheater when the throttle is closed, and, at such time, means must be provided to prevent damage to the superheater units. This is accomplished by partitioning off the superheater flues from the tubes in the tube-sheet by plates *a*, Fig. 22, and by providing a damper *b* at the bottom of the enclosure thus formed. With the damper closed, there is no draft through the superheater flues, and so they are not overheated. A mechanism is provided to open the damper as soon as the throttle is opened and to close the damper as soon as the throttle is closed.

As shown in Fig. 23, the damper *a* is supported by shafts *b* and *c* that are carried in bearings *d* and *d'*; the former is secured to the outside of the smokebox and the latter to the inside. A damper-shaft arm *e* (also see Fig. 24) with a counterweight *f* at the extreme end is keyed to the end of the shaft *c*. One end of the damper-shaft link *g* is connected to a bearing on the damper-shaft arm and the other end is connected to the outside damper-cylinder arm *h*. This arm is keyed and pinned to a shaft *i* to which is also connected the inside damper-cylinder arm *j*. The end of this arm rests upon and is operated by the piston *k* in the cylinder *l*, which is in communication with the steam pipe of the locomotive through the pipe *m*. When the throttle is opened, the steam passes to the damper cylinder and moves the piston *k* upwards. The piston moves the inside damper-cylinder arm *j* upwards, which rotates the shaft *i*, and the outside damper-cylinder arm *h*. The link *g* then moves the damper-shaft arm upwards and opens the damper by rotating the shaft *c*. A view of the damper shaft *c* is shown in Fig. 25. The damper is held in the jaw of the shaft by the bolt shown.

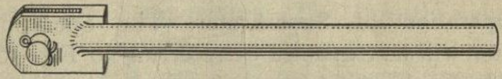


FIG. 25

**62.** It is particularly important that the damper mechanism be properly installed and maintained. If the mechanism does not close the damper properly, the gases will not be prevented from entering the superheater flues when the throttle is closed. Also, if the damper does not open properly, the engine will not steam freely, owing to the obstruction that is offered to the passage of the gases.

The damper will sometimes open and close when the locomotive is drifting at short cut-off. With the reverse lever well hooked up, the cylinder compression will be higher than when the lever is farther down. Then when the valve opens the port and preadmission occurs, the air and steam in the cylinder will pass up into the steam chest, the steam pipe, and the damper cylinder, and the damper will open. This action may result in the return bends of the superheater units being overheated to such an extent that they may burst when the throttle is opened, especially if any water is carried over into the units. The remedy is to drift with the reverse lever farther forwards in the corner.

**63. Operation of Superheater.**—The operation of the superheater will be explained by referring to Fig. 16, in which the superheater header is shown partly broken away and with one superheater unit connected to it. The saturated-steam compartments are indicated by *j* and the superheated-steam compartments by *i*, and, as already explained, one pipe *b* of each superheater unit is connected to an opening in a saturated-steam compartment and the other pipe *b'* is connected to a similar opening in the adjoining superheated-steam compartment.

The passageway *g* and all the saturated-steam compartments *j* fill with steam from the dry pipe *d* as soon as the throttle is opened. The steam then passes through each of the openings in these compartments to the pipe *b* of a superheater unit, and is superheated in its passage through the unit by the gases that are passing through the flue *k*. The superheated steam returns to the header through the pipe *b'* of a superheater unit and enters a superheated-steam compartment, from whence it passes into passage *h* to the steam pipes that are coupled to the header at *e* and *f*. The temperature of the steam is increased about 250° in its passage through the superheater, hence the steam must lose this degree of superheat before it begins to condense.

The superheating of the steam is not accompanied by any increase in the pressure, although the molecules of steam are now vibrating much faster. As already stated, the pressure will remain the same, provided the molecules of steam are permitted to move farther apart as they are heated. The constant withdrawal of the steam from the superheater to meet the requirements of the cylinders, gives the steam molecules in the superheater more room to expand as they are heated, hence there is no increase in pressure. Also, the steam drops slightly in pressure when it passes from the boiler and expands into the volume of the superheater, and this fact also helps to offset any tendency for the pressure to increase above normal. A superheater when properly designed will not cause the pressure to increase, neither will it cause the pressure to decrease.

## SUPERHEATER ARRANGEMENT WITH FRONT-END THROTTLE VALVE

**64. Reason for Arrangement.**—The throttle valve, when a superheater is used, may be placed in the steam dome as in ordinary practice, or it may be placed between the superheater header and the steam pipes to the steam chests. This location places the throttle valve at the front end of the locomotive; it is therefore known as a front-end or smokebox throttle valve.

A superheater with a front-end throttle valve has several advantages over one with the ordinary arrangement of throttle valve. When a front-end throttle valve is applied, the superheater damper and rigging are not used because, with the valve between the superheater and the cylinders, the superheater units are always filled with steam. Furthermore, at all times there are one or more of the auxiliaries and the blower working; therefore, steam is flowing through the units when the main throttle valve is closed, thus affording protection to the superheater units. Only when such protection is afforded, however, may the damper be dispensed with without the danger of overheating the superheater units. From the viewpoint of maintenance the presence of steam in the units at all times, greatly reduces the possibility of burning the unit ends and tends to protect the equipment and prolong the life of the tubing.

Superheated steam can also be supplied to the locomotive auxiliaries, such as the headlight-turbine, air compressor, water pumps, stokers, steam grate shaker, blower, whistle, etc. Tests indicate that the use of superheated steam in the auxiliaries decreases their demand on the boiler by 40 per cent., which is equivalent to a saving of from 4 to 8 per cent. of the total fuel burned. Also, the front-end throttle valve enables the locomotive to be more easily controlled because of the small volume of steam that is left to pass to the cylinders when the throttle is closed. Therefore, slipping can be stopped almost instantly; also, the locomotive can be spotted more easily.

The front end throttle valve may be incorporated with the type E superheater header as explained in the following sections or it may be separate from it.

## ELESCO TYPE E LOCOMOTIVE SUPERHEATER

**65. Difference Between Type A and Type E Superheaters.** The difference between the Elesco type A and E superheaters consists primarily in the size and disposition of the superheater units and the boiler flues. Each superheater unit comprises eight tubes of a diameter of $1\frac{1}{8}$ or $1\frac{3}{16}$ inches, two of which tubes are placed in a flue; four flues are therefore required to accommodate a complete unit. The superheater flues occupy nearly the whole flue sheet area, and are smaller than those used with the type A superheater, having an outside diameter of 3 inches, $3\frac{1}{4}$ inches or $3\frac{1}{2}$ inches. A larger number of units is consequently used than with the type A superheater.

The principal advantage of this arrangement is an increase of from 15 to 20 per cent. in the total gas area through the flues, an increase of from 35 to 40 per cent. in the steam area through the superheater, and an increase of from 80 to 100 per cent. in the superheating heating surface.

The increase in the heating surface not only imparts a higher degree of superheat to the steam, but it also has the effect of evaporating the large percentage of moisture that is carried over into the superheater owing to the restricted steam space in the large modern boilers. Because of clearance limitations, the steam dome has become smaller and smaller, so that on large locomotives practically all there is of a steam dome is a cap that serves as a manhole for entering the interior of the boiler. A boiler of this construction is therefore limited in steam space and the percentage of moisture carried over to the superheater is much greater than it is on the older or smaller locomotives, where the boiler is provided with ample dome or steam space, thereby providing much drier saturated steam to the superheater.

The type E superheater gives a degree of superheat from 250° F. to 300° F. as compared with a degree of superheat of from 200° F. to 250° F. obtained with the type A. The increase in the steam area through the superheater lessens the drop in steam pressure from the boiler to the cylinders.

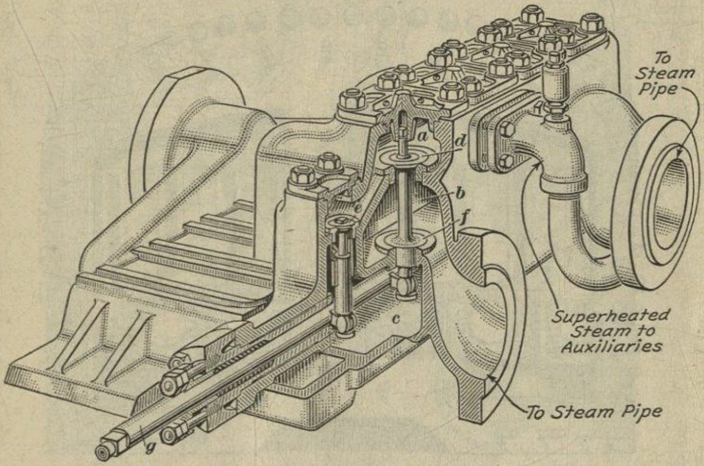


FIG. 26

The front-end throttle valve is used with the type E superheater, hence a damper and a damper mechanism is not necessary.

**66. Superheater Header.**—With the type of header used with the type E superheater, shown partly broken away in Fig. 26, the American multiple throttle is integral with the casting. The only change, as far as the arrangement of the superheater is concerned, is that the unit bolts are reversed, the nut being placed on top of the header instead of below the clamp.

With this type of header a smokebox coverplate is provided above the header as shown in Fig. 27, so that the unit bolt nuts as well as the throttle are accessible from the top of the smokebox. The American multiple throttle, as the name implies, consists of a series of small single-seated valves that are located in the forward part of the superheater header. There are three longitudinal chambers that extend across the front of the header and that are arranged one above the other. The upper chamber *a*, Fig. 26, is part of the superheated-steam section of the superheater header. At the front of this chamber are the flange connections for the pipe that conveys steam to the auxiliaries, so that superheated steam is always available for them. The middle chamber *b* connects to the steam pipes; the third chamber *c* is without outside connection and is used entirely for balancing. There are three or more main valves *d* each $4\frac{1}{8}$ inches in diameter; these admit steam from the upper to the middle chamber. At the extreme left is a smaller valve *e* known as the pilot valve, that admits steam from the upper chamber to the balancing chamber. Each of the main valves has a balancing piston *f* that fits loosely in the passage between the middle chamber and the balancing chamber.

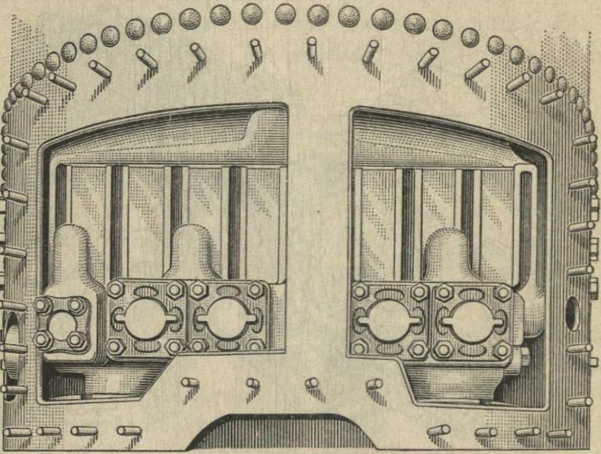


FIG. 27

**67.** The valves are opened and closed successively by a camshaft *g* and they are so balanced that a minimum effort is required to lift them. At the first movement of the camshaft the small pilot valve *e* is lifted, which, because of its small size, offers little resistance. Steam is then admitted into the balancing chamber and under the pistons *f* of the main valves. The areas of the pistons are such that the main valves are now nearly balanced. As the cam-shaft is rotated further the first main valve is lifted, thereby allowing a small amount of steam to pass to the cylinders. A further rotation of the shaft opens the main valve at the opposite end of the chamber and continues the lifting of the first valve; thus, in succession all of the valves are lifted. The closing takes place in the reverse order. By the successive opening and closing of the valves, positive graduation of the steam is provided to the cylinders.

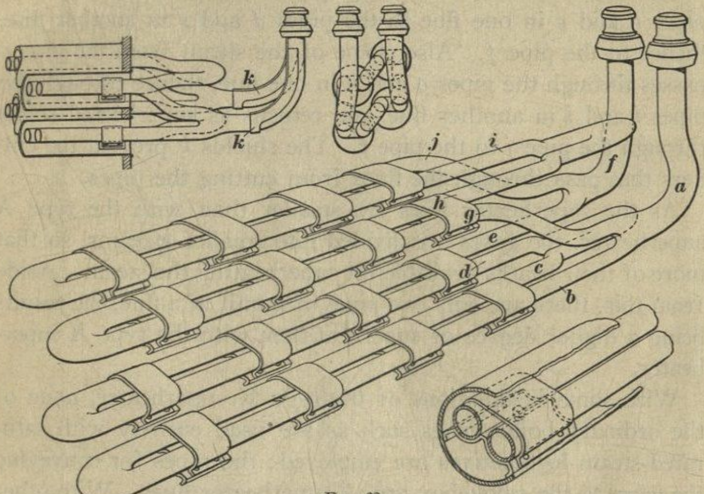


FIG. 28

The valves can be repaired with the boiler under pressure; to do so it is only necessary to close the shut-off valve in the dry pipe at the steam dome, and then open the throttle and cylinder cocks to drain the steam from the superheater units.

To guard against excessive pressure in the superheater should the shut-off valve be closed without opening the throttle and the cylinder cocks, a safety valve is provided in the pipe that conveys superheated steam to the auxiliaries.

**68. Unit Arrangement.**—A view of a superheater unit used with the type E superheater is shown in Fig. 28. With the type A superheater, a complete unit consisting of four pipes is placed in each flue, whereas with the type E superheater, a unit comprises eight pipes, with two in each flue, therefore a single superheater unit occupies four flues.

The saturated steam enters the pipe *a* and passes through the pipes *b* and *c* in one flue to the pipes *d* and *e* in another flue, thence to the pipe *f*. Also, some of the steam from the pipe *a* passes through the pipes *g* and *h* in one flue, thence through the pipes *i* and *j* in another flue, and returns as superheated steam through the pipe *j* to the pipe *f*. The shields *k* prevent the cinders that pass through the flues from cutting the pipes.

As the superheater flues are smaller than with the type A superheater, the gases are divided into smaller streams, so that more of their heat is available for superheating the steam. Aside from this, there are only two pipes of a unit in a flue, the results being a higher degree of superheat than with the type A superheater.

With some installations of the type E superheater, none of the ordinary boiler tubes such as are used entirely with saturated-steam locomotives are employed; the pipes for conveying the gases to the smokebox are all superheater flues. With other installations, a few of the ordinary type of tubes are used.

**69. Pressure in Type E Superheater.**—With the type E superheater and the throttle closed, the pressure of the steam in the superheater will increase slightly, as the steam cannot expand except toward the boiler. However, the volume of steam in the superheater is so small as compared with the steam volume in the boiler, that the slightly higher pressure of the small volume in the superheater does not perceptibly affect the pressure of the larger volume in the boiler.

**70. Arrangement.**—A sectional view of the casting of a Chambers front-end throttle valve in the smokebox forward of

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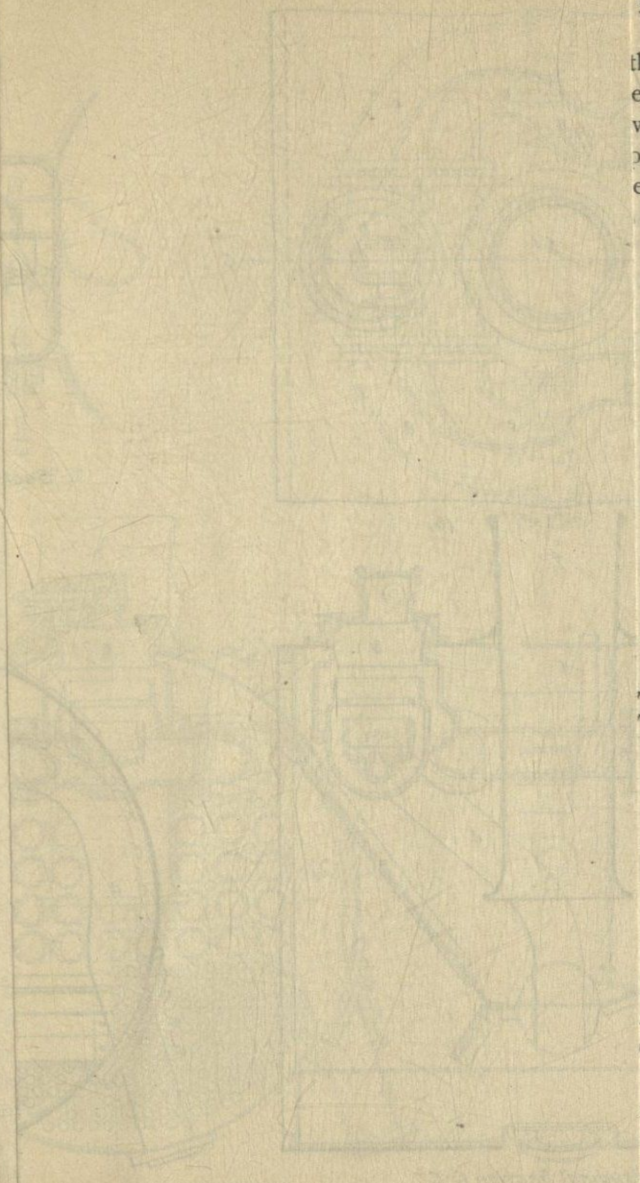

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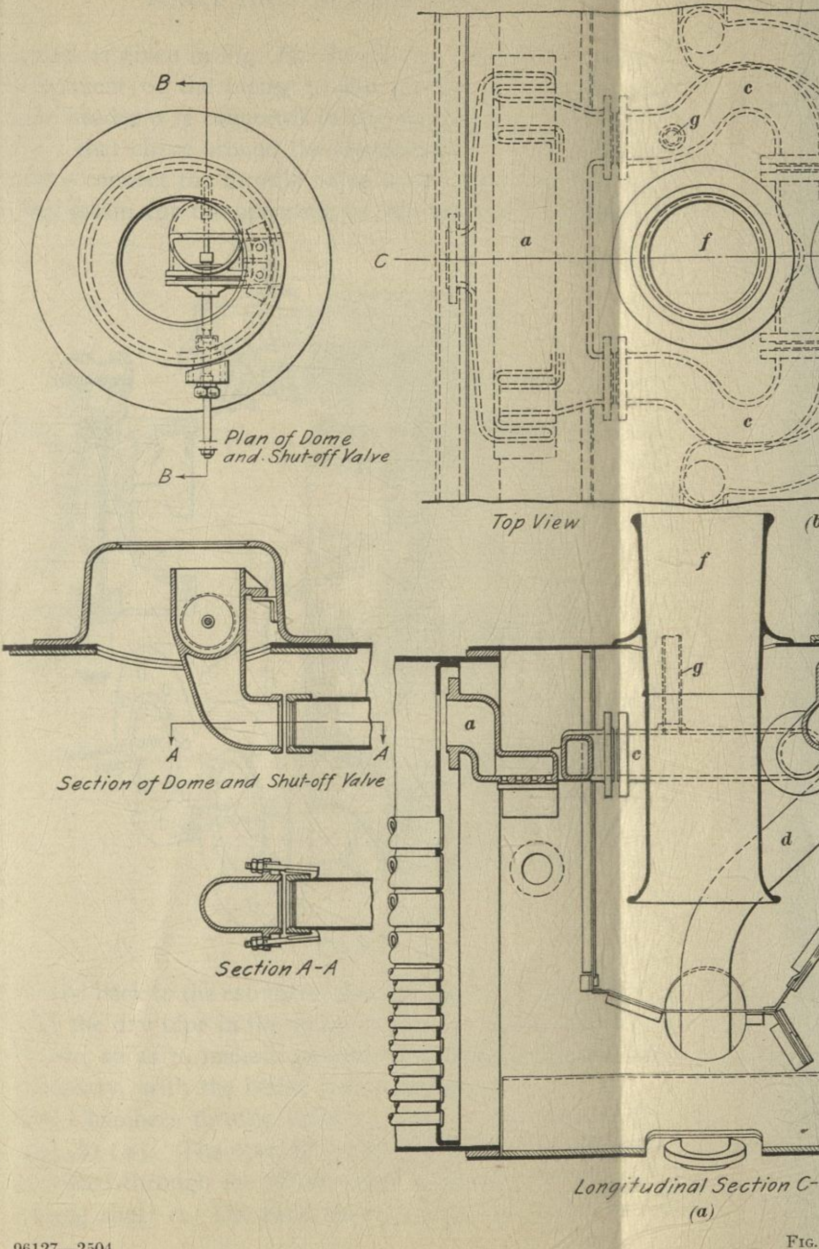
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Plan of Dome and Shut-off Valve
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Section of Dome and Shut-off Valve
Section A-A
Longitudinal Section C-
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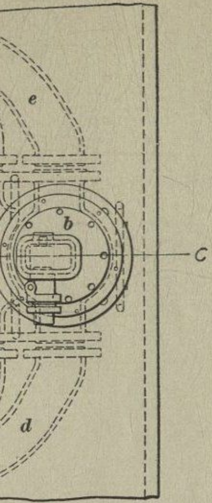
FIG.



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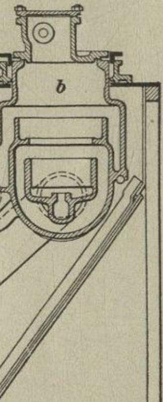
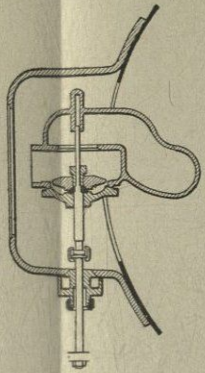
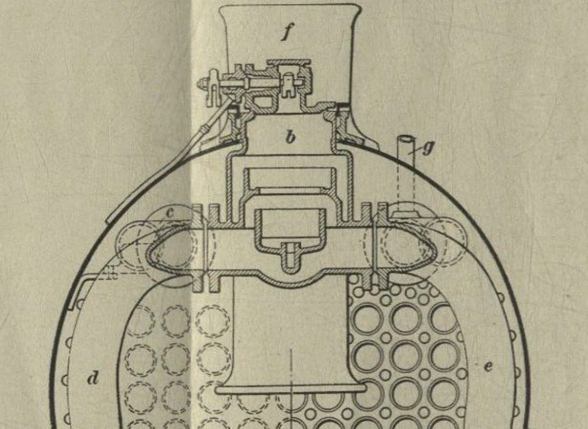




Section B-B



Front End in Half Section

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the stack is given in Fig. 29. In the top view (*b*) is shown the arrangement of the piping to the throttle valve. The superheater header *a* is connected to the throttle valve *b* by the two pipes *c* that curve around the smokestack *f*. The steam pipes *d* and *e* connect the throttle valve to the steam chests. Superheated steam for the operation of the locomotive auxiliaries is conveyed back to the cab turret through the $2\frac{1}{2}$-inch pipe *g*. The end of the dry pipe in the steam dome is provided with a shutoff valve, so as to make it possible to repair the throttle valve, if necessary, with the boiler under pressure.

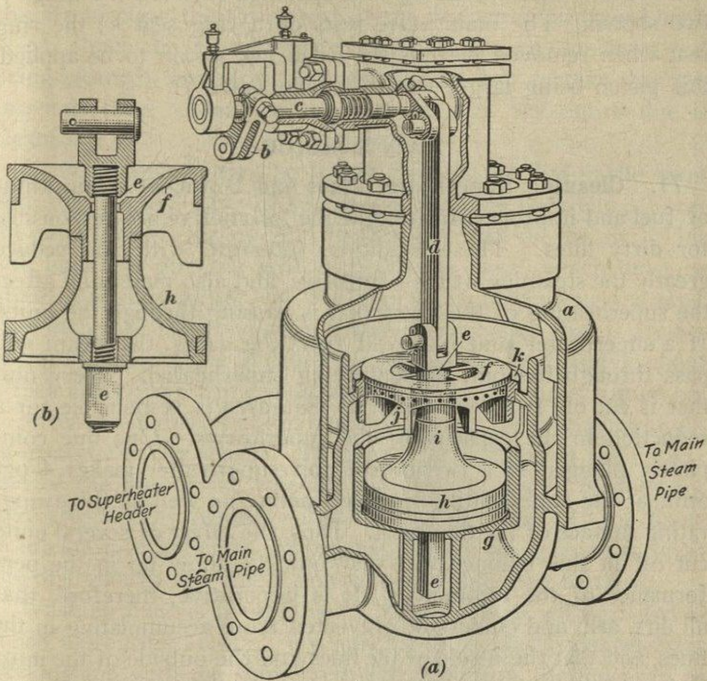

FIG. 30

The Chambers throttle valve is shown in its throttle box *a* in Fig. 30 (*a*). The opening movement of the throttle lever is transmitted through the throttle rod to the crank arm *b* on the operating shaft *c*. The shaft then lifts the link *d* and the pilot valve *e* (also see view (*b*) ), and permits steam to pass through the center of the main valve *f* to the chamber *g* under the balancing piston *h*. The pilot valve next pulls the balance piston upwards until its end comes in contact with the main valve at *i* and unseats it. The steam first passes through the series of small holes shown in the main valve; as the valve continues to lift, the steam passes through the openings between the wings *j*, two shown. The main valve rests on a ring seat *k*; the ring seat when removed permits the balancing piston to be applied, this piston being larger than the main valve *f*.

## MAINTENANCE

71. **Cleaning Superheater Flues and Units.**—Certain kinds of fuel and improper drafting of the locomotive are responsible for dirty flues. These conditions interfere with and reduce greatly the steaming of the locomotive, and also materially affect the superheating of the steam that is passing through the units. If a superheater unit is cut off from the gases, the steam will pass through the unit without being superheated. Every unit that is cut off from the action of the gases is responsible for a reduction in the capacity of the superheater. One flue completely plugged in a twenty-five unit superheater makes 4 per cent. of the superheating surface inactive as well as the evaporating surface of the flue itself. Thus, the effect of several units cut off in this manner will very quickly show up in the performance of the locomotive. It is imperative, therefore, that all dirt, ash, and cinders be prevented from accumulating in the flues, and that the inside of the flues and the outside of the units be kept clean and free from soot. Any accumulation of clinkers or cinders on the back end of the return bend should be broken off and removed from the firebox end.

72. To clean a flue, the procedure is as follows: Insert a $\frac{3}{8}$-inch or $\frac{1}{2}$-inch air pipe at the firebox end of the flue, turn on the air, which should be at a pressure of 100 pounds or more, and gradually work the pipe forwards under the superheater unit and for the whole length of the flue, thereby allowing the air to blow the dirt ahead of the cleaning pipe out of the front

end of the flue and out through the damper, which must be open during the operation. The damper must be closed afterwards.

When a flue is plugged up, dig the dirt out from the back end until the return bends of the unit are reached, drawing the dirt back into the firebox. Then, if possible, force the cleaning pipe through the dirt to the front end of the flue. Apply the air and slowly draw the pipe back about 2 feet so as to allow the air to clear the front end of the flue as it is drawn back. Next, shove the pipe forwards again to insure the front end being cleaned, then draw it slowly back 2 feet farther than the previous time. Continue this process until the entire flue is cleaned.

If the air pipe cannot be forced through the flue to the front end, the flue will have to be cleaned from the back end. Force the pipe about 6 inches into the dirt and turn on the air. This will blow the dirt out with considerable force, which must be guarded against to prevent injury to the man handling the pipe. A 9-inch disk of wood with a hole in its center that is a close fit for the air pipe, will prove a good guard. It should be about ½ inch away from the end of the flue when the air is turned on.

After the flues have been cleaned, use a good bright flashlight to inspect for cleanliness. Holding a torch flame at the firebox end of the flue to see whether the flame is drawn in does not give trustworthy evidence that the flue is clean. If the flame is drawn in, it indicates simply that there is an opening through the flue, though the whole bottom of the flue may be filled.

Washing flues is preferable to blowing them with air and is much more satisfactory. By washing at regular boiler washout periods and with the same crew and apparatus, the flues can be kept clean and in a more satisfactory condition from washout to washout. After washing the flues, insert an air hose in each one to insure drying up the moisture; otherwise there will be difficulty when firing up.

73. **Testing the Superheater.**—Leakage of steam from the flues, flue-sheet seams, rivets, superheater units, or the dry-pipe and steam-pipe joints, has a tendency to cut through any other part of the metal that it strikes against, so that such a leak may

result in serious damage unless it is promptly discovered and remedied. The only reliable way to detect such leaks in time to prevent damage is to test the superheater units, steam pipe, exhaust pipe, and dry pipe, at regular intervals, by use of water at a pressure of 100 pounds or more. In many cases serious leaks have been found in the front end that must have existed for some time without resulting in a steam failure and without affecting the steaming of the locomotive sufficiently to cause a "poor steaming" report to be made.

The tests for leaks should be made at quarterly inspections. If the boiler is warm, hot water should be used for the test. The water can be admitted into the boiler either through the connection used for filling the boiler or through the blow-off. When more than 100 pounds pressure is obtained, a careful inspection should be made of the dry-pipe joints, steam-pipe joints, exhaust-stand joint, exhaust-nozzle tip, the joint between the superheater units and the header, and all seams and flues in the front end. At the back end, the return bends in the superheater units should be inspected, and any water in the bottom of the flue under the unit ends should be considered an indication of a leak in the unit.

# HEAT AND SUPERHEATERS

Serial 2504 Edition 1

## EXAMINATION QUESTIONS

**Notice to Students.**—*Study the Instruction Paper thoroughly before you attempt to answer these questions.* **Read each question carefully and be sure you understand it;** *then write the best answer you can. When your answers are completed, examine them closely, correct all the errors you can find, and* **see that every question is answered;** *then mail your work to us.*

(1) Name some of the advantages of a front end throttle valve.

(2) To what is the term *heat* applied?

(3) What is the unit of rate of doing work called, and how much work does it represent?

(4) What is the term *temperature* used to indicate?

(5) What instrument is generally used to measure temperature?

(6) What name is given to the quantity of heat unit and what increase in temperature does it represent?

(7) What is the advantage of superheating steam?

(8) Name the three different ways in which heat may be transmitted.

(9) How many foot-pounds of work constitute one British thermal unit?

(10) What is meant by the degree of superheat?

(11) What is the purpose of the superheater header?

(12) What is the purpose of the locomotive superheater?

(13) What is the purpose of the superheater units?

(14) Name the parts of a superheater.

(15) What is steam?

**Mail your work on this lesson as soon as you have finished it and looked it over carefully. DO NOT HOLD IT until another lesson is ready.**

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Our students need paper on which to write lessons; many of them need drawing outfits, chemistry outfits, chemical and other supplies that are not included with their Courses. Many inquiries therefore arise as to the kind of supplies to purchase and where to get them.

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